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ULTRASONIC DEFECT SIZING USING DECIBEL DROP METHODS: VOLUME III: FATIGUE CRACKS

by

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Research report

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ABSTRACT

An earlier study on the use of ultrasonic decibel drop sizing methods for determining the length and vertical extent of flaws in welded steel sections was based on the scanning of machined flaws and fabrication flaws.

The present study utilized the techniques developed to perform a similar study of the type of flaws expected to develop during service (e.g. fatigue cracks).

The general findings are that:

a) the use of decibel drops of less than 14 dB generally undersize the length of fatigue cracks; and

b) the use of decibel drop methods to determine vertical extent is questionable.

RÉSUMÉ

Une étude antérieure sur l'utilisation de diverses méthodes d'évaluation ultrasonique par réduction du signal acoustique pour déterminer la longueur et l'étendue verticale des défauts dans les soudures de sections d'acier se basait sur l'examen de défauts artificiels et de fabrication.

La présente étude a utilisé les techniques mises au point pour exécuter une analyse semblable du genre de défauts auxquels on s'attend en cours d'utilisation, par exemple, les fissures dues à l'usure.

Les résultats généraux de l'étude sont que:

a) la réduction du signal acoustique inférieure à 14 dB sous-estime généralement la longueur des fissures dues à l'usure;

b) le recours aux méthodes d'évaluation par réduction du signal acoustique est douteux pour déterminer l'étendue verticale des défauts.

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RPC Job No. 10000750/0001
Date: March 31, 1988

INTRODUCTION

A variety of decibel drop techniques are currently in use for ultrasonic sizing of flaws in welds during the periodic inspection of Canadian nuclear power plants. Due to the diversity of techniques and their application, the accuracy and repeatability of using these techniques in sizing flaws has been questioned. In an effort to gain insight into the relative merits of each technique, AECB sponsored a study at RPC (Project 85.1.9) . In part of this study, various dB drop sizing methods were used on both artificially introduced flaws and a selection of welding fabrication flaws. General conclusions regarding dB drop methods were as follows:

(i) Decibel drop methods of sizing, for either length or vertical extent, produce accurate results only when the flaw dimension being measured is larger than the sound beam width striking the flaw.

Decibel drop methods cannot determine accurately the length or vertical extent of a flaw when the dimension being measured is smaller than the width of the sound beam at the flaw. Attempts by dB drop methods to determine the length or vertical extent of a flaw, which is smaller than the beam width striking the flaw, will result in measuring the width of the sound beam, not the dimensions of the flaw.

For flaws of actual vertical extent less than the sound beam width, the ultrasonic vertical extent will be erroneous and equal to the width of the sound beam striking the flaw. Plotting of this erroneous data by beam centre line displays an oversized flaw. Plotting of this erroneous data by the beam profile method displays an undersized flaw. Neither plotting method displays the true flaw vertical extent or orientation.

(ii) For real weld flaws, having dimensions larger than the sound beam, decibel drop methods of 14 to 20 dB appear to give the most accurate assessment of length. This compares with the 14 dB and 20 dB drops for accurate length measurement of EDM slots and semi-elliptical saw cuts respectively. For real weld flaws, general implementation of 20 dB drop method for assessing flaw length does not appear practical because of the tendency of very small discontinuities in a "dirty" weld to contribute to the echo envelope and extend the apparent length of the flaw. It is recommended that the dB drop method based on a 14 dB drop from maximized indication amplitude be used to assess flaw length.

Based on sizing a single artificial flaw of large vertical extent, the dB drop method of 14 dB appears to give the most accurate results. Plotting of vertical extent by the beam centre line method yields the most accurate display of flaw vertical extent and orientation. Plotting by beam profile methods displays vertical extents which are considerably smaller than the actual vertical extent of the flaws. It is recommended that vertical extent be plotted by the beam centre line method.

For large planar flaws, decibel drop methods work best when the sound beam is directed to strike the flaw at normal incidence. Since the orientation of the flaw is unknown, several angles should be used.

AECB subsequently requested RPC to carry out a small extension to the above program. The objective of this extension was to ascertain if the above conclusions are still valid when flaws which may be expected to develop in-service (ie fatigue cracks) are sized by dB drop methods. The present report is concerned with the results of this program extension.

2. METHODOLOGY

The methodology used in the present program closely followed that used in the earlier study. (1)

In further developing the system of recording the ultrasonic scans, it was decided to replace the X-Y recorder with a more automated method. The new system involves a three channel analog to digital (A/D) converter connected to a computer which automatically records the scan information.

A Position Displacement Transducer (PDT) was employed to monitor probe movement by producing an analog signal proportional to the position of the probe.

As before, the HP digital counter provided the analog signal for CRT distance and the peak amplitude analog signal came directly from the USL38.

When a scan was performed, the data from these three channels (probe position, CRT distance, and peak amplitude) was recorded by the computer, filtered, and the envelope trace plotted on the computer screen.

Fig. 1 shows the improved system in use scanning a fatigue crack. Fig. 2 shows an example of a length scan plotted on the computer screen.

The improvements introduced greatly speeded up the scanning and processing of data.

To ensure that plots obtained from the improved system were consistent with those obtained earlier, test blocks with artifical defects were rescanned. Examples of the plots obtained from Test Plate 5 with the present and previous methods are given in Appendix A. Very good correlation was found between the scans confirming that the change in the system had minimal effect.

Details of calibration and flaw scanning methods are given in the previous report (1). Ultrasonic equipment used was also the same except for the substitution of transducer serial number 40291.

The plots of vertical extent given in Appendices A and B also contain additional information regarding changes in CRT distance, more details of this are given in section 8.2 of reference (1).

3 TEST PLATES CONTAINING FATIGUE CRACKS

3.1 General

The original intention was to obtain samples of large diameter piping welds and by applying fatigue cycling cause them to crack in the weld region. Previous experience with service failures led us to believe that the most likely site for fatigue cracking was along the weld, either on the outside surface initiated at the weld toe or the inside surface initiated at the weld root.

However, the preparation of fatigue cracks of satisfactory length, depth and orientation in the laboratory proved to be much more difficult than anticipated. Five coupons cut from power piping were fatigued at Nova Scotia Research Foundation. Numerous fatigue cracks were formed of which only three proved satisfactory for the present program. Two submarine steel welds, the property of Defence Research Establishment Atlantic and which had been fatigued in a previous research program by Nova Scotia Research Foundation, were loaned to RPC. These welds provided two further satisfactory examples of fatigue cracks.

A particular problem associated with producing laboratory fatigue cracks was that the ratio between length and depth was much larger than would be expected from a semi-elliptical crack shape. Consequently many cracks were too shallow to even attempt to carry out vertical extent scans. Another problem was that cracks most easily formed at plate edges and other stress raisers such as machining marks left during profiling of the pipes for welding and were consequently awkwardly positioned for scanning.

3.2 Test Plate NBPIPE-1

This test plate consisted of good quality large diameter carbon steel piping of nominal 0.75 inch thickness,

five inches wide and fourteen inches long. A circumferencial butt weld running across the pipe had been made using Pt. Lepreau GS welding procedures.

Fatigue cycling produced two cracks on the convex surface of the pipe running transverse to the weld. The longer of these cracks (Flaw #1) was selected for examination. To allow scanning across the weld, the inside and outside surfaces were carefully ground to remove the weld cap and root.

Flaw #1 is shown in Fig. 3. The crack is revealed by flourescent magnetic particle techniques. This revealed surface length was taken as the "actual length". A variety of ultrasonic techniques, including crack tip diffraction, were applied to Flaw #1 to determine its depth. A concensus of all these measurements was used to establish "actual depth".

The essential dimensions of Test Plate NBPIPE-1 are as follows:

Pipe thickness:	20 mm
Crack location:	convex surface/transverse to weld
Dimension of Flaw #1:	actual length = 27mm
	actual depth = 11 mm

3.3 Test Plate NBPIPE-2

This consists of good quality large diameter carbon steel piping of nominal thickness of 0.75 inches thickness, six inches wide and fourteen inches long. A circumferential butt weld running across the pipe had been made using Pt. Lepreau GS welding procedures. The inside surfaces of both pipes had been machined with a chamfer to bring the thickness of the pipe down to a nominal half inch at the weld.

Fatigue cycling produced numerous cracks on the inside surface of the pipe. Long shallow fatigue cracks were formed along the edge of the weld root and also along machine marks on the chamfer. These were too shallow for the present study. Numerous edge cracks were also formed. One of these, Flaw #1 was selected for scanning as the deepest crack available. Because it was an edge crack, it was not suitable for length scanning.

Flaw #1 is shown (specimen edge) in Fig. 4 with the crack revealed by flourescent magnetic particle techniques. At the pipe edge the depth was measured as 14mm but at the point of scanning, a variety of ultrasonic techniques applied indicated the depth to be 11 mm. This latter figure was taken as the "actual depth".

The essential details of Test Plate NB PLATE-2 are as follows:

Pipe thickness: 20 mm tapering to 14mm
Crack location: at edge of pipe segment penetrating from inside (concave) surface
Dimensions of Flaw #2: actual depth = 11mm

3.4 Test Plate NSRF-1

This consisted of two pieces of HY 90 low alloy submarine steel welded together to form a flat plate 20 inches long by 11 inches wide. The weld caps were completely removed before fatiguing. Two significant cracks were formed running transverse to the weld. The shortest one (12mm long), was chosen as the shortest to be scanned in the present program.

Flaw #1 is identified in Fig. 5. The cracks are revealed by flourescent magnetic particle technique. The measured length of the crack on the surface (12 mm) was taken to be the "actual length". A variety of ultrasonic

techniques was used to determine an "actual depth" of 7.5 mm.

The essential details of Test Plate NSRF-1 are as follows:

Plate thickness: 26 mm
Crack location: top side transverse to weld
Dimension of Flaw #1: actual length = 12 mm
actual depth = 7.5 mm

3.5 Test Plate NSRF-2

This consisted of two pieces of HY90 low alloy submarine steel welded together to form a flat plate 20 in long by 11 inches wide. The weld caps had been completely removed before fatiguing. The plate contained two significant cracks and numerous small cracks running transverse to the weld. The largest one was choosen to represent a mid sized fatigue crack for the purposes of this program.

Flaw 1 identified in Fig. 6. The cracks are revealed by flourescent magnetic particle techniques. The measured length of the cracks (17mm) was taken as the "actual length". A variety of ultrasonic techniques were used to establish the "actual depth" (7 mm).

Essential details of Test Plate NSRF-2 are as follows:

Plate thickness: 26 mm
Crack location: top side of plate
transverse to weld
Dimensions of Flaw #1: actual length = 17 mm
actual depth = 7 mm

4. SCANNING

4.1 General

Examples of fatigue cracks of varying severity were scanned in accordance with the procedures used in the earlier investigation. Scans were made with 45^{o}, 60^{o} and 70^{o} probes and from the cracked side (designated "top") and from the uncracked side (designated "bottom") of the plates. Skip distances were confined to half-skip and one-skip in order to keep beam spread comparable to or less than the vertical extent of the fatigue cracks.

The scans from the four defects examined are given in Appendices B to E .

4.2 Length Determination

Satisfactory length determinations were made of fatigue cracks 12 mm, 17 mm and 27 mm long using the guidelines established previously. In agreement with the earlier study, lengths determined by the -14 dB method slightly oversized the cracks, lengths determined by the -6 dB and other dB levels undersized the cracks. The results from the present study consequently confirmed those reported previously.

It was found that length scans from the fatigue cracks seemed more "noisy" than those from machined defects possibly due to their non-planar nature. Profiles obtained using larger angles appeared to be better defined than those obtained with the 45^{o} probe.

4.3 Vertical Extent

The previous study emphasized the difficulty in obtaining satisfactory vertical extent measurements because of the effect of beam width. The present study confirmed these difficulties. Vertical extent values comparable with

the actual depth of the defects were only obtained where the (projected) beam width was minimized. Thus it is extremely difficult to have any confidence that the values of vertical extent obtained represented anything but beam widths.

The scans of vertical extent obtained from fatigue cracks were noticeably more "noisy" than those obtained from machined defects.

5. CONCLUSIONS

5.1

The length of fatigue cracks can be determined quite accurately by using the -14 dB drop-off technique previously recommended.

5.2

The present study confirmed the difficulty reported in the previous study in obtaining satisfactory measurements of vertical extent because of the relative magnitude of beam width and defect size.

5.3

Scans obtained from fatigue cracks are generally similar to those from machined defects.

6. REFERENCE

(1) Ultrasonic Defect-Sizing Using Decibel Drop Methods Vols. 1 and 2 by R.V. Murphy, March 1987, AECB Report. INFO-0250-2.

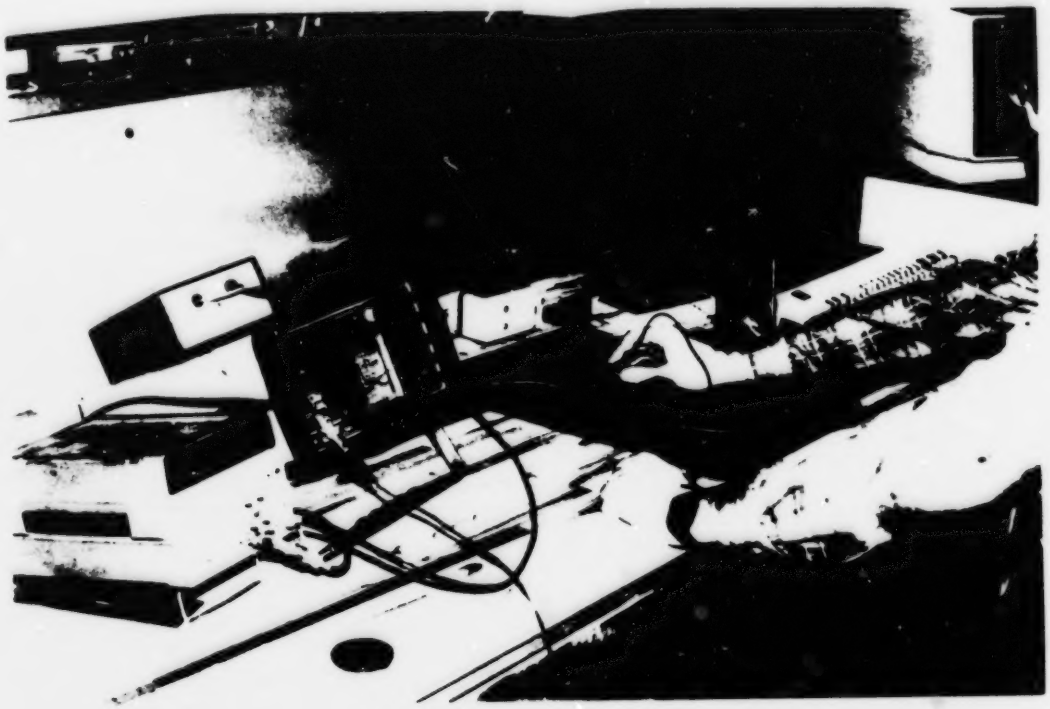


FIGURE 1: Scanning Equipment in Use on Test Plate NSRF - 1

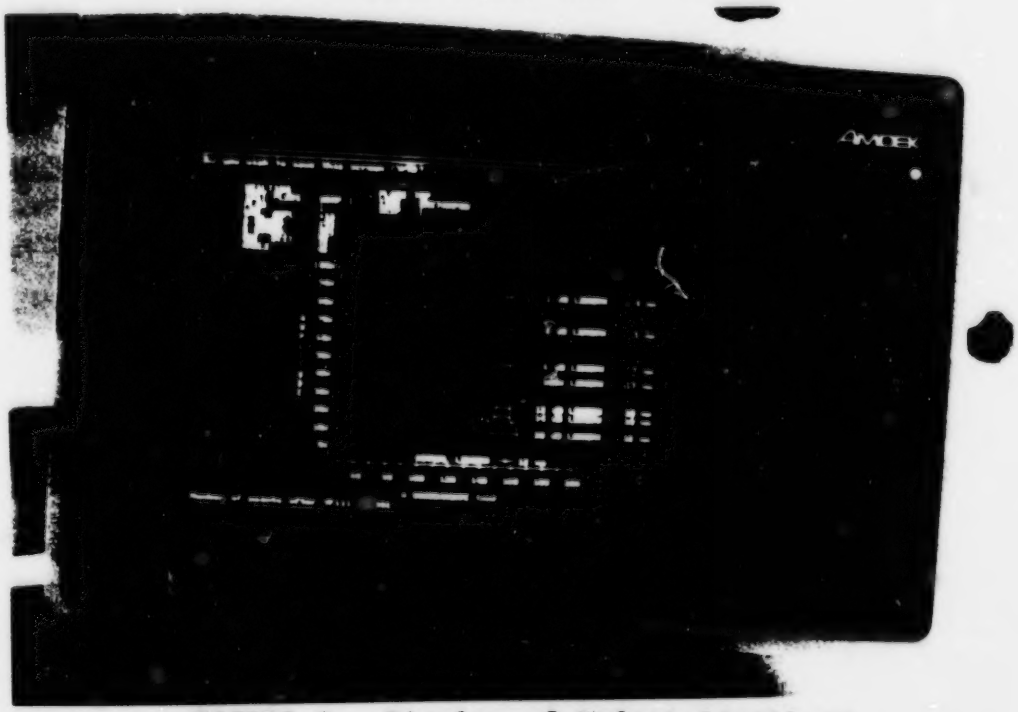


FIGURE 2: Display of Defect Length on Computer Screen

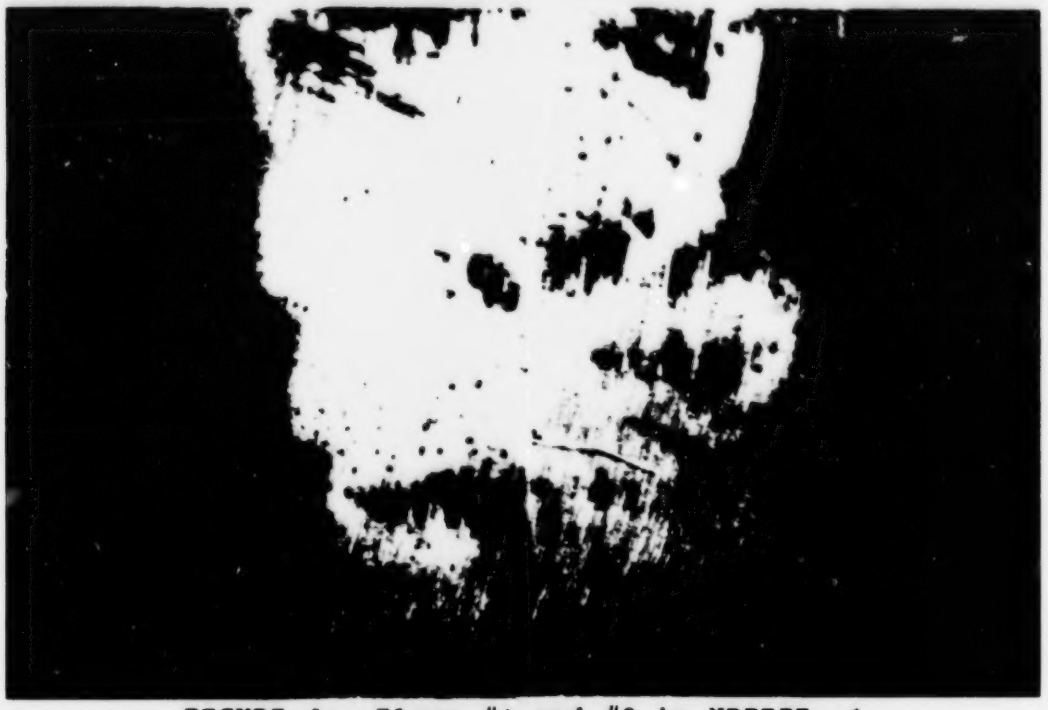


FIGURE 3: Flaws #1 and #2 in NBPIPE -1

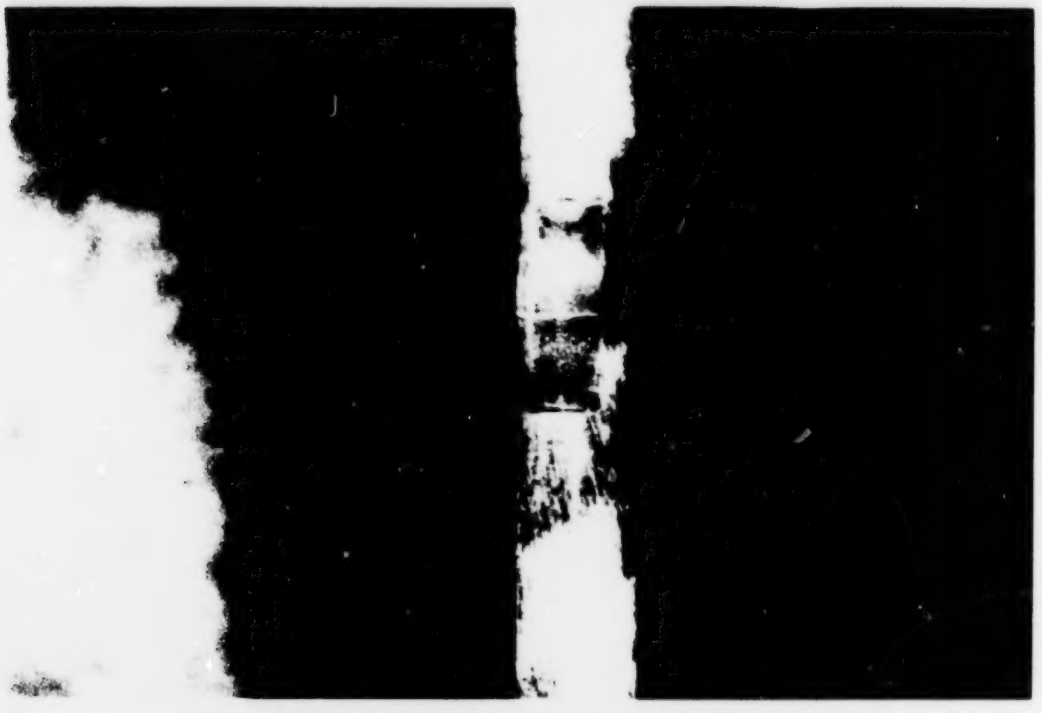


FIGURE 4: Side View of Pipe Showing Depth of Flaw #1, NBPIPE -2

FIGURE 5: Flaws #1 and #2
Test Plate NSRF - 1

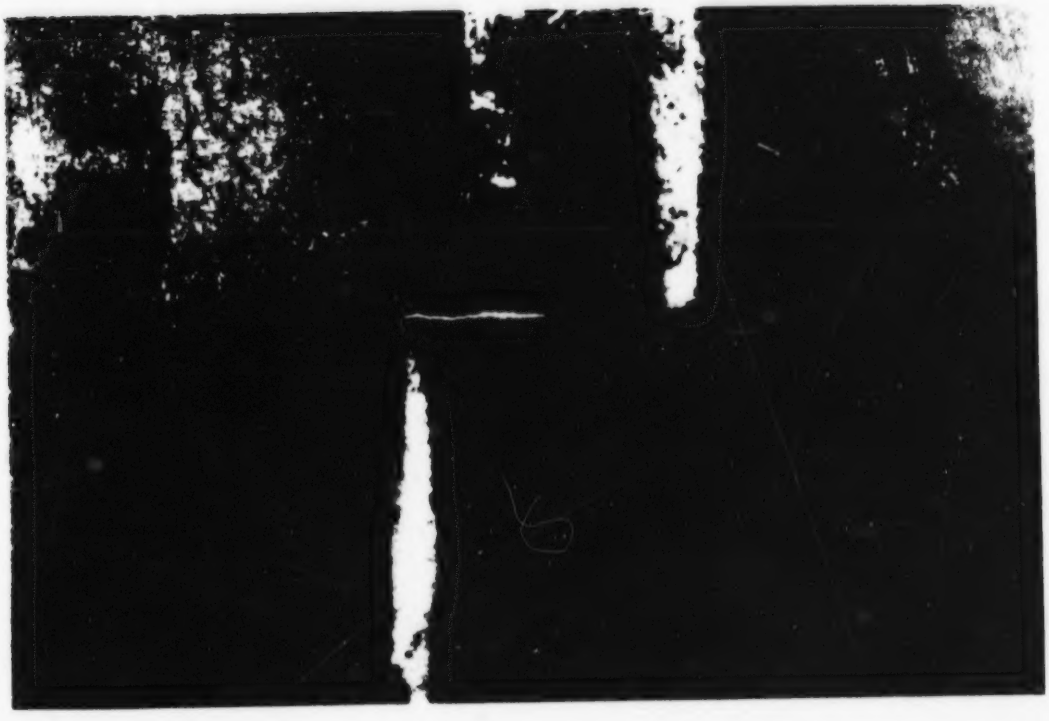
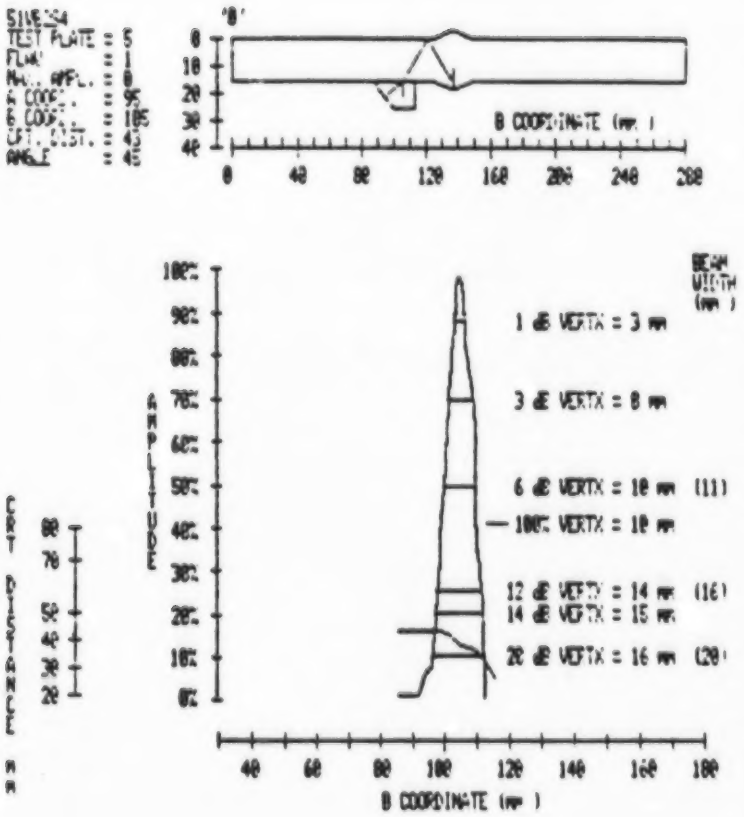


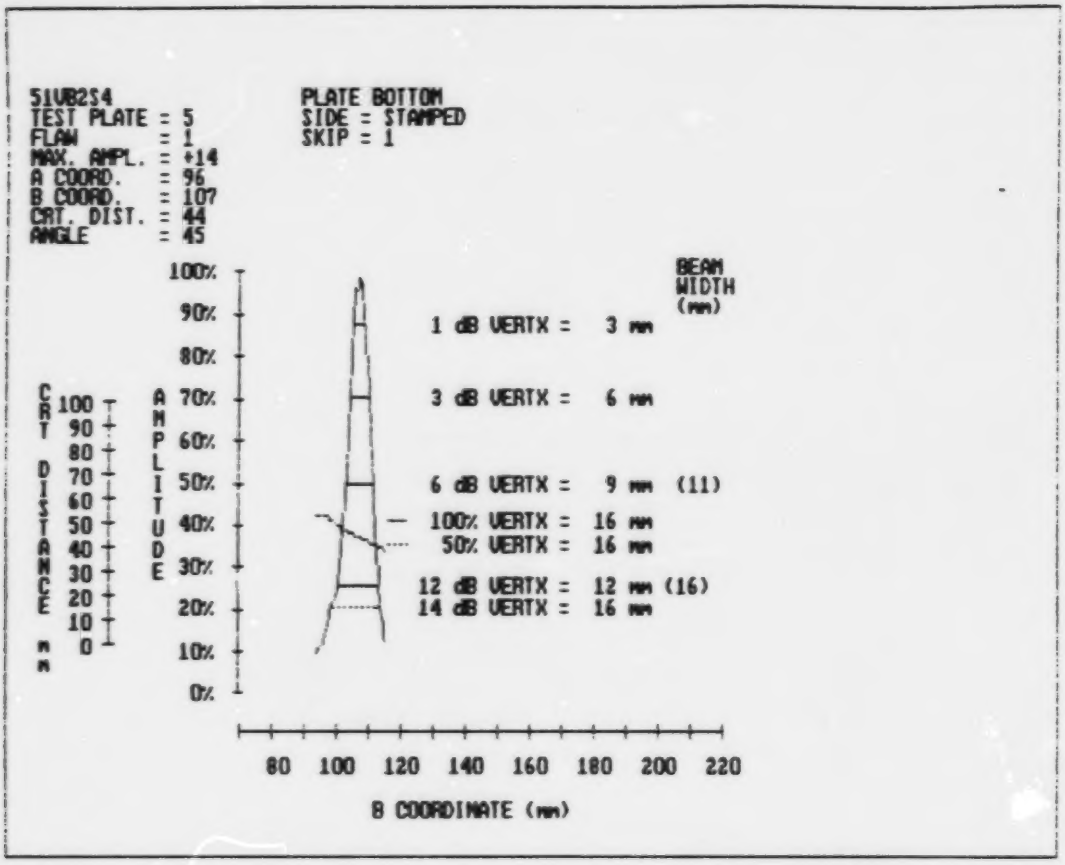
FIGURE 6: Flaw #1 Test Plate NSRF -2

APPENDIX A

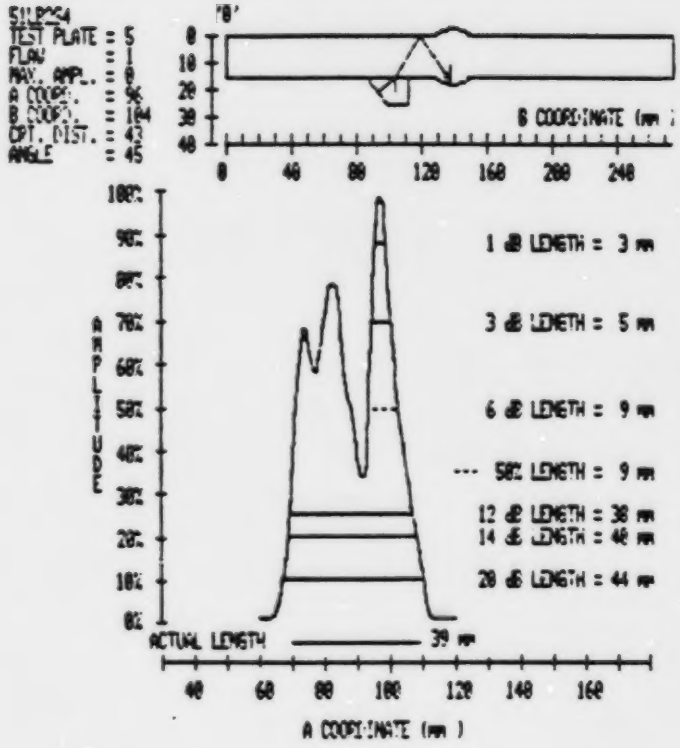
Correlation Between Defect Scans Obtained With Improved Method and Previous Method


TEST PLATE = 5
FLAW = 1
'B'
B COORDINATE (mm)
AMPLITUDE
BEAM WIDTH (mm)
1 dB VERTX = 3 mm
3 dB VERTX = 8 mm
6 dB VERTX = 10 mm (11)
100% VERTX = 10 mm
12 dB VERTX = 14 mm (16)
14 dB VERTX = 15 mm
20 dB VERTX = 16 mm (20)
B COORDINATE (mm)

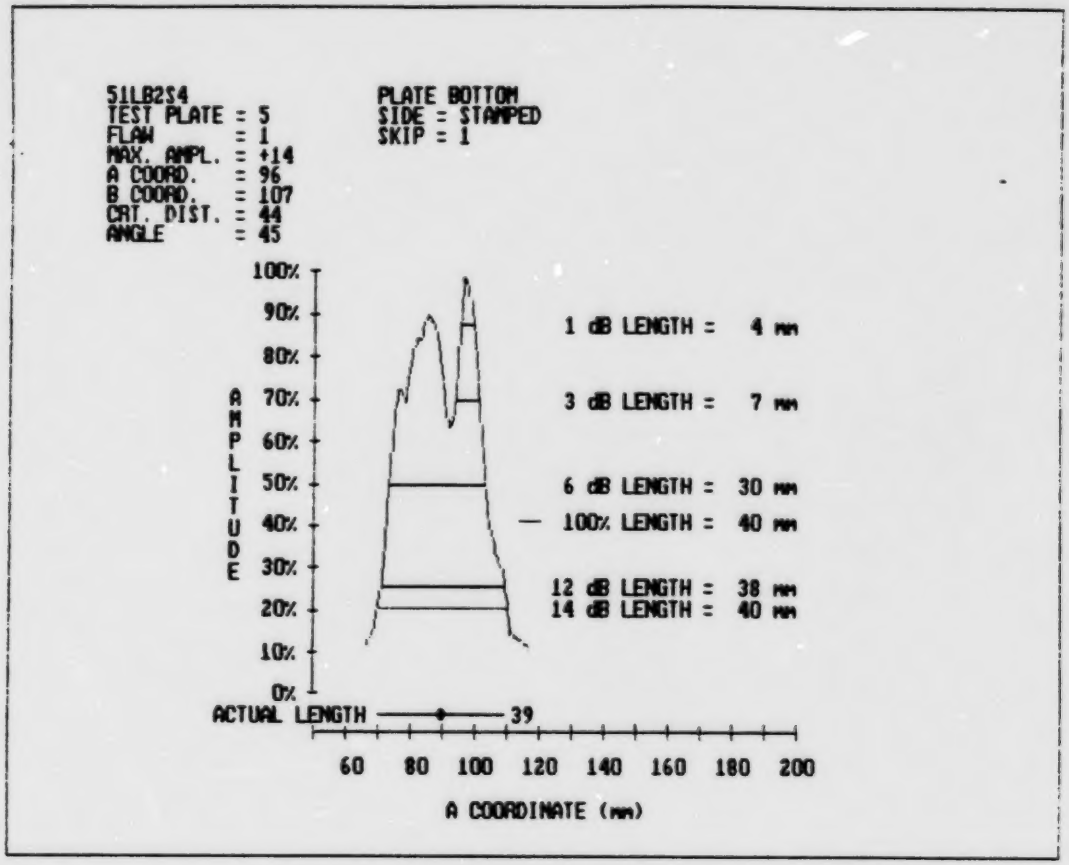
A1(a) Flaw 1 Test Block 5 Vertical Scan Obtained in Previous Study



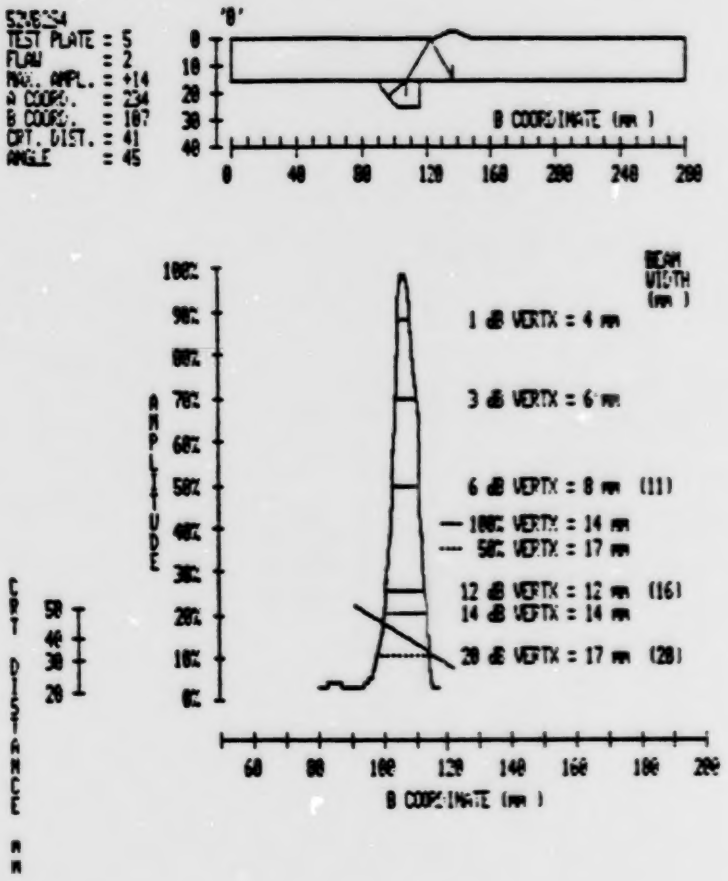
A1(b) Flaw 1 Test Block 5 Vertical Scan Obtained with Modified Equipment is Very Close to Scan Shown in A1(a).


TEST PLATE = 5
FLAW = 1
'B'
B COORDINATE (mm)
1 dB LENGTH = 3 mm
3 dB LENGTH = 5 mm
6 dB LENGTH = 9 mm
--- 50% LENGTH = 9 mm
12 dB LENGTH = 38 mm
14 dB LENGTH = 40 mm
20 dB LENGTH = 44 mm
ACTUAL LENGTH 39 mm
AMPLITUDE
A COORDINATE (mm)

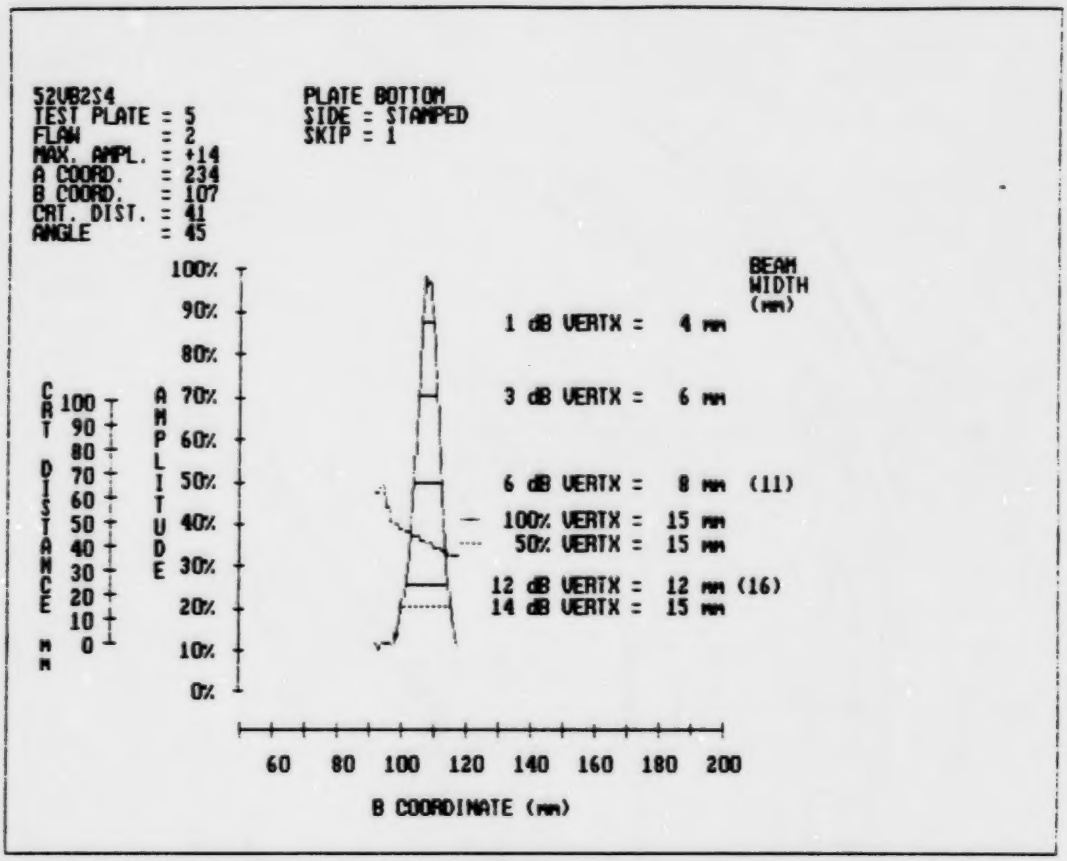
A2(a) Flaw 1 Test Block 5 Linear Scan Obtained in Previous Study.



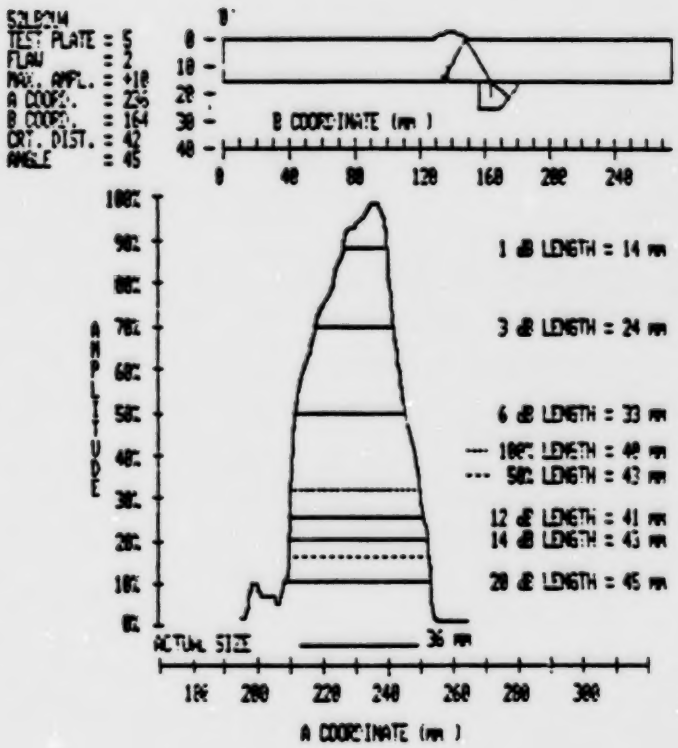
A2(b) Flaw 1 Test Block 5 Linear Scan Obtained with Modified Equipment is Very Close to That Shown in A2(a)


TEST PLATE = 5
FLAW = 2
MAX. AMPL. = +14
A COORD. = 234
B COORD. = 107
CRT. DIST. = 41
ANGLE = 45
'B'
B COORDINATE (mm)
AMPLITUDE
BEAM WIDTH (mm)
1 dB VERTX = 4 mm
3 dB VERTX = 6 mm
6 dB VERTX = 8 mm (11)
100% VERTX = 14 mm
50% VERTX = 17 mm
12 dB VERTX = 12 mm (16)
14 dB VERTX = 14 mm
20 dB VERTX = 17 mm (28)
CRT DISTANCE mm

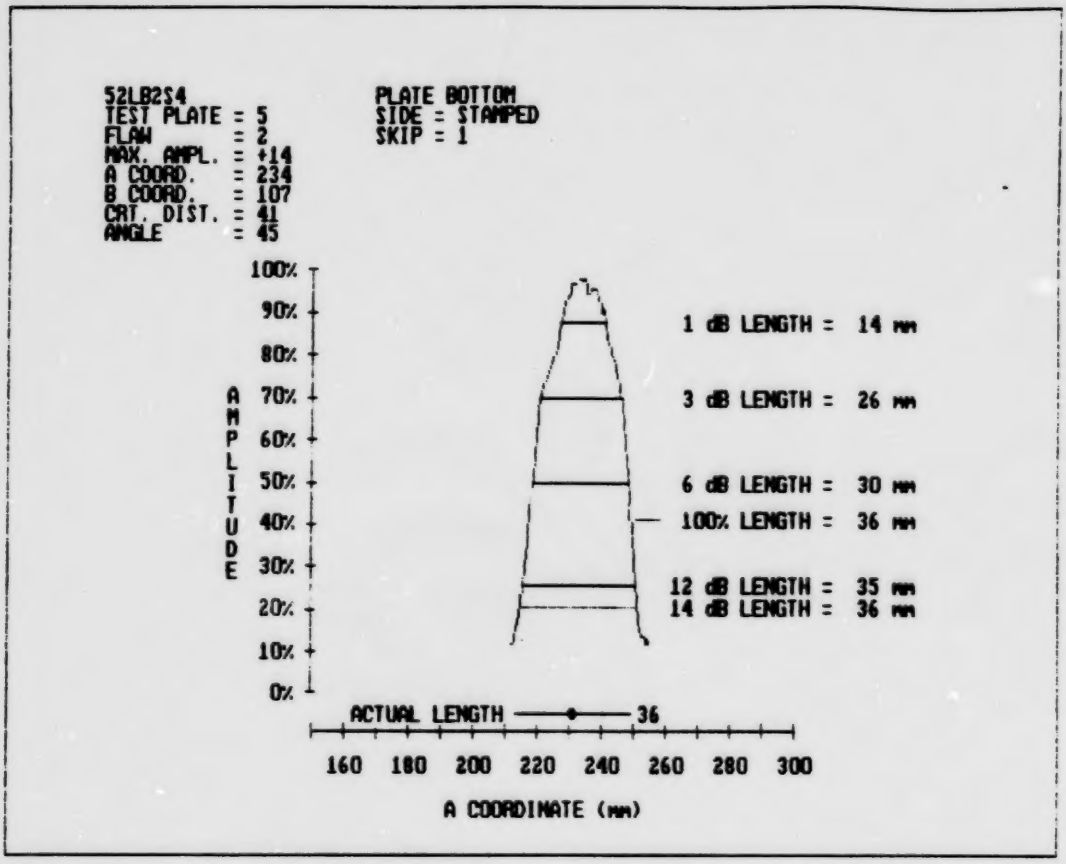
A3(a) Flaw 2 Test Block 5 Vertical Scan Obtained in Previous Study



A3(b) Flaw 2 Test Block 5 Vertical Scan Obtained with Modified Equipment is Very Close to Scan Shown in A3(a).



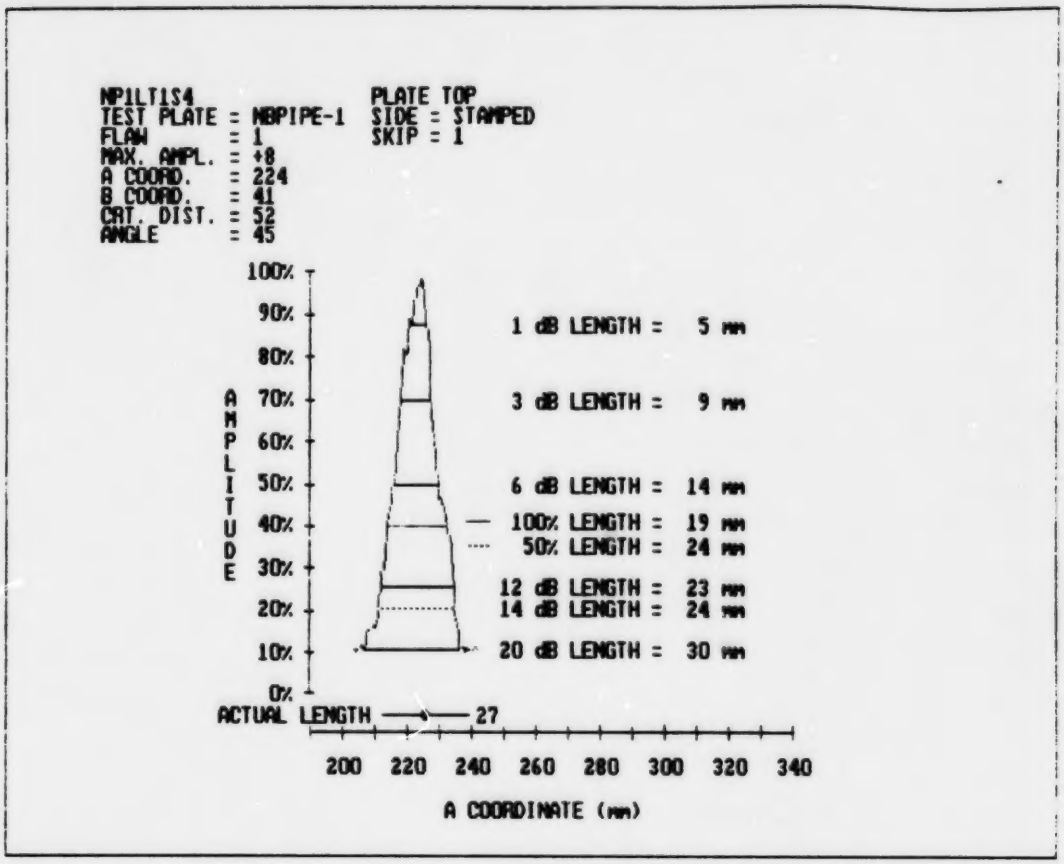
A4(a) Flaw 2 Test Block 5 Linear Scan Obtained in Previous Study

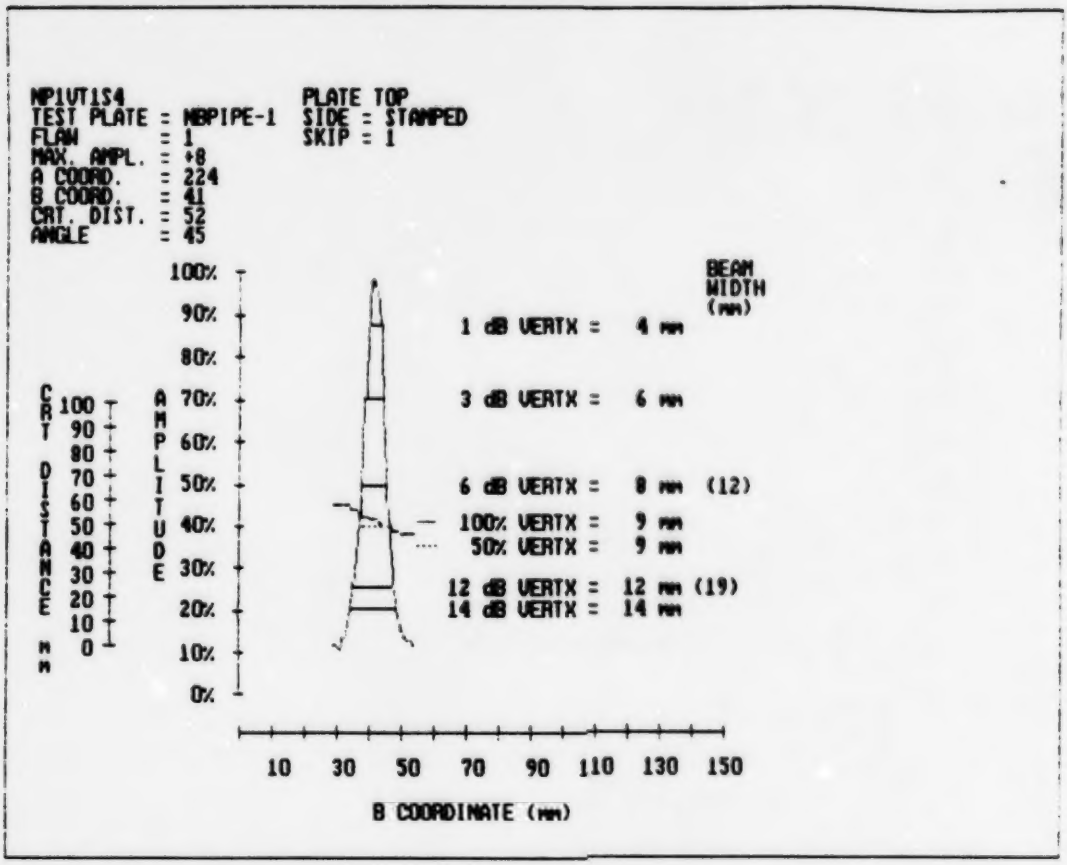


A4(b) Flaw 2 Test Block 5 Linear Scan Obtained with Modified Equipment is Close to that Shown in A4(a)

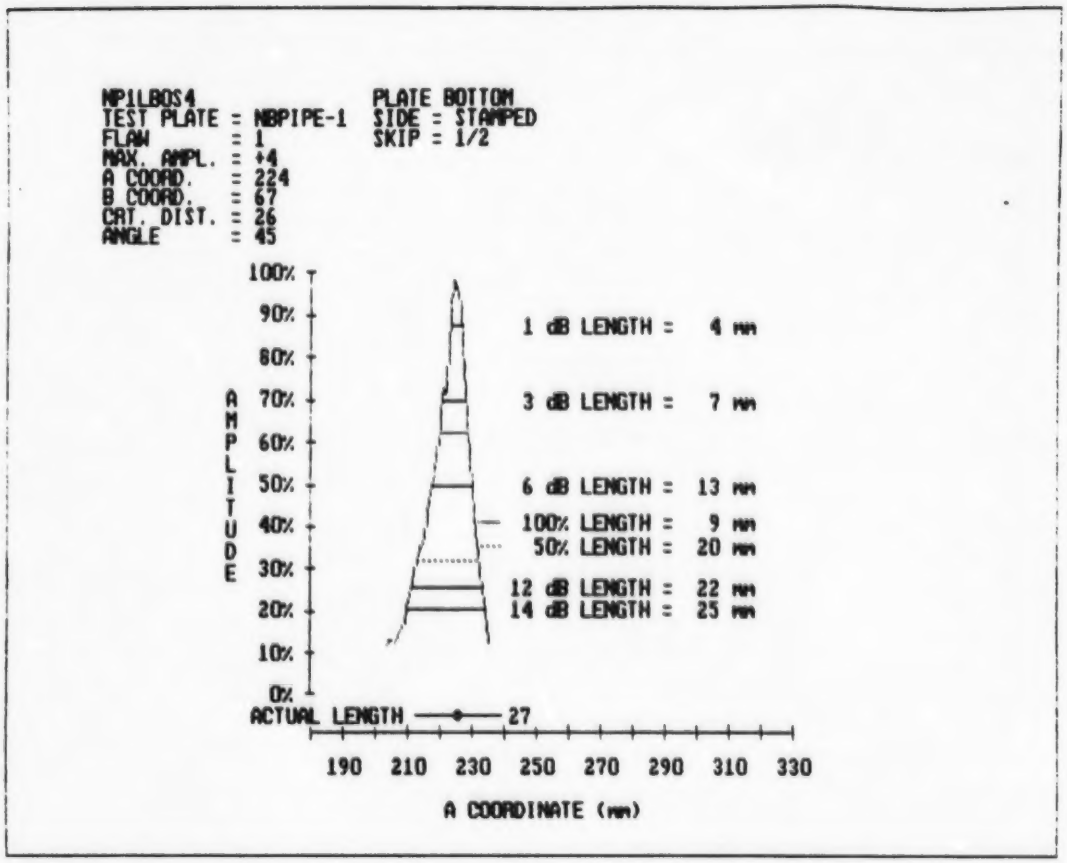
APPENDIX B

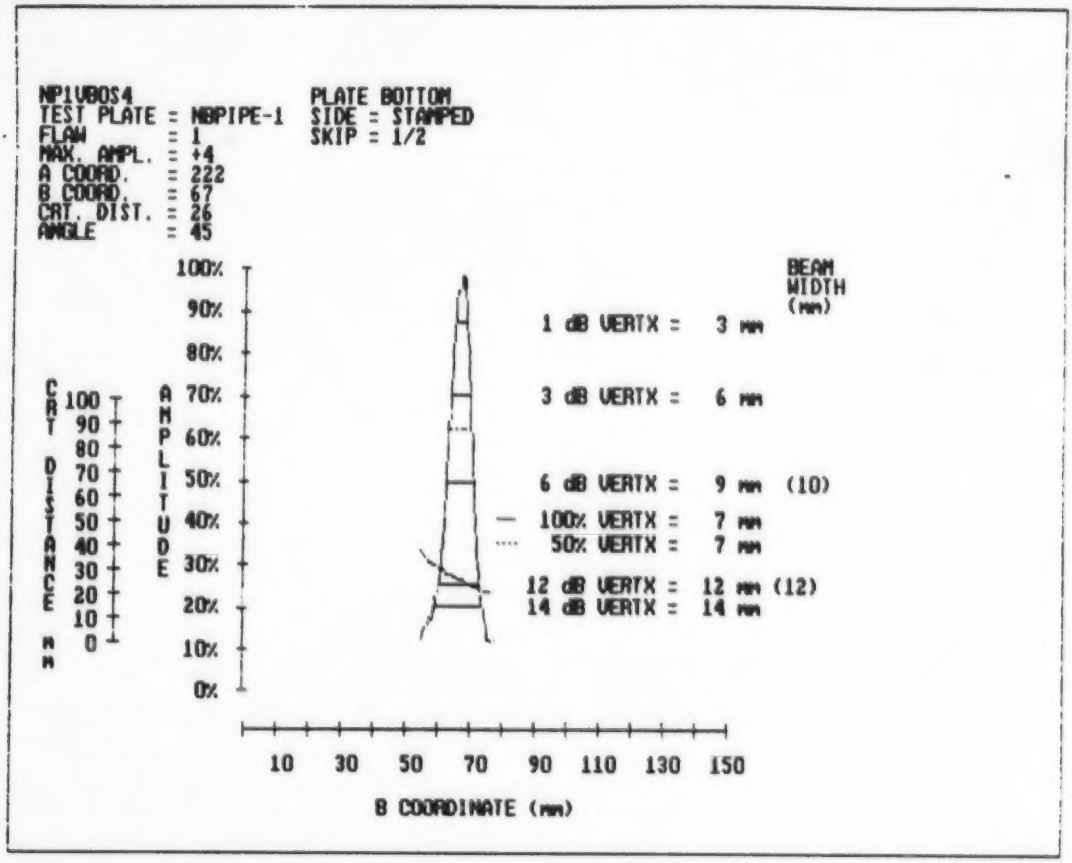
Ultrasonic Scans Obtained From Flaw #1 NBPIPE - 1


NP1LTLS4
TEST PLATE = NBPIPE-1
FLAW = 1
MAX. AMPL. = +8
A COORD. = 224
B COORD. = 41
CRT. DIST. = 52
ANGLE = 45
PLATE TOP
SIDE = STAMPED
SKIP = 1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 5 mm
3 dB LENGTH = 9 mm
6 dB LENGTH = 14 mm
100% LENGTH = 19 mm
50% LENGTH = 24 mm
12 dB LENGTH = 23 mm
14 dB LENGTH = 24 mm
20 dB LENGTH = 30 mm
ACTUAL LENGTH — 27
200 220 240 260 280 300 320 340
A COORDINATE (mm)

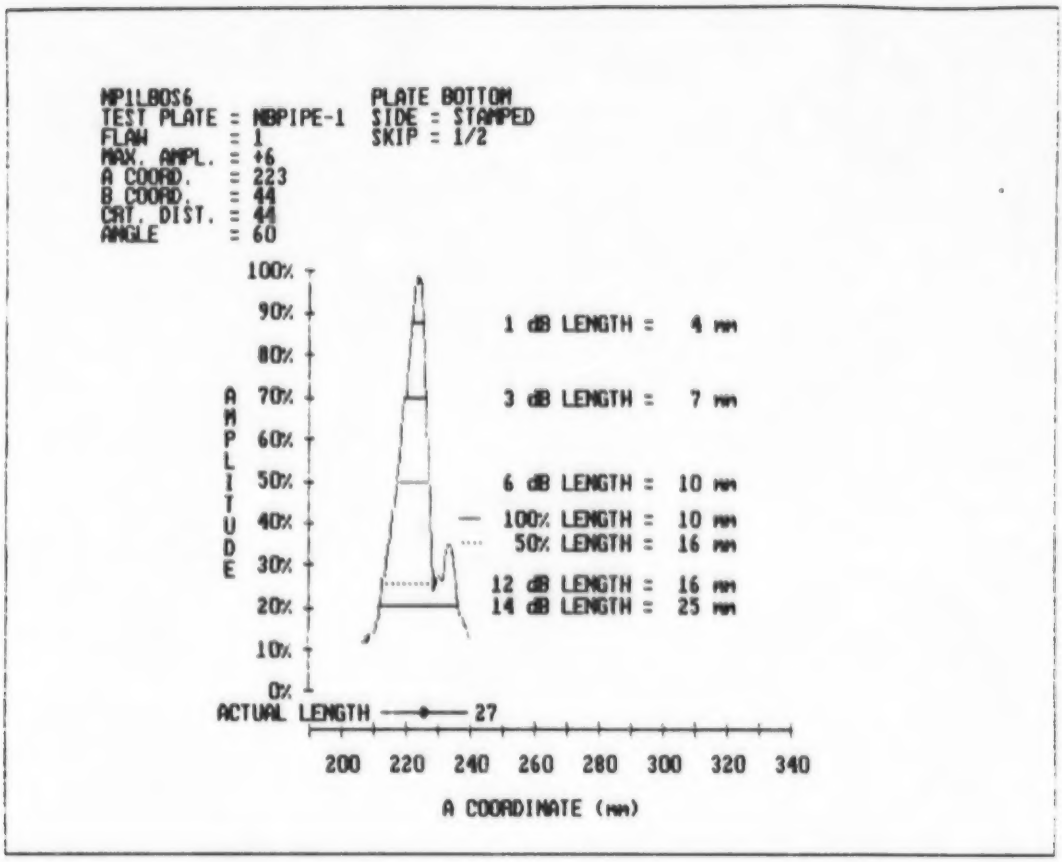


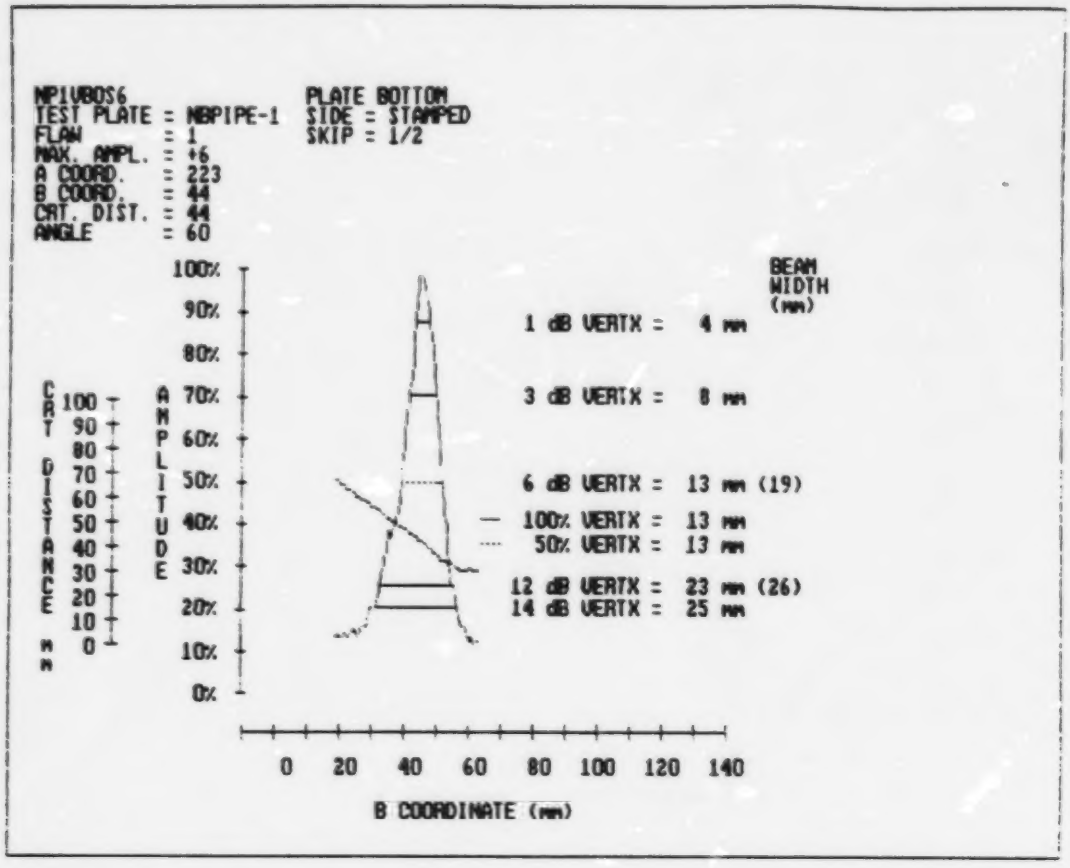
ACTUAL VERTICAL EXTENT EQUALS 11MM


NP1LBOS4
TEST PLATE = NBPIPE-1
FLAW = 1
MAX. AMPL. = +4
A COORD. = 224
B COORD. = 67
CAT. DIST. = 26
ANGLE = 45
PLATE BOTTOM
SIDE = STAMPED
SKIP = 1/2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 4 mm
3 dB LENGTH = 7 mm
6 dB LENGTH = 13 mm
100% LENGTH = 9 mm
50% LENGTH = 20 mm
12 dB LENGTH = 22 mm
14 dB LENGTH = 25 mm
ACTUAL LENGTH 27
190 210 230 250 270 290 310 330
A COORDINATE (mm)



ACTUAL VERTICAL EXTENT EQUALS 11MM

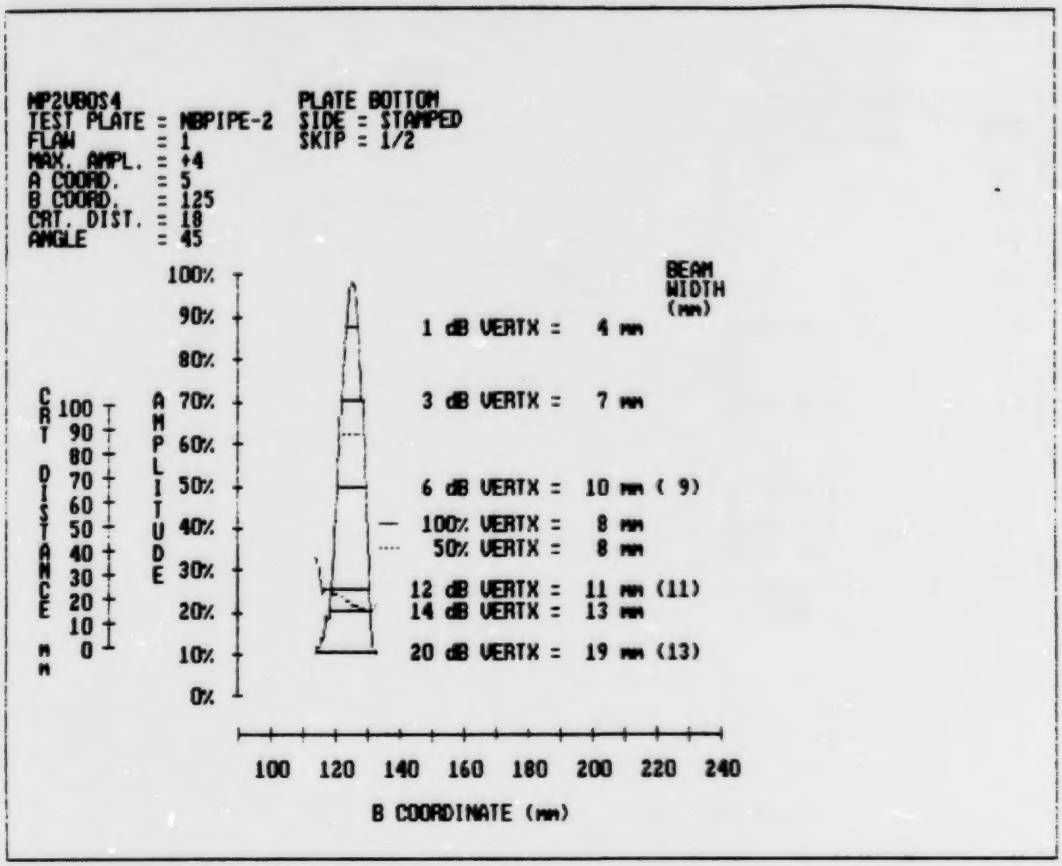

MP1LBOS6
TEST PLATE = MBPIPE-1
FLAW = 1
MAX. AMPL. = +6
A COORD. = 223
B COORD. = 44
CAT. DIST. = 44
ANGLE = 60
PLATE BOTTOM
SIDE = STAMPED
SKIP = 1/2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 4 mm
3 dB LENGTH = 7 mm
6 dB LENGTH = 10 mm
100% LENGTH = 10 mm
50% LENGTH = 16 mm
12 dB LENGTH = 16 mm
14 dB LENGTH = 25 mm
ACTUAL LENGTH 27
200 220 240 260 280 300 320 340
A COORDINATE (mm)


MP1UBDS6
TEST PLATE = NBPIPE-1
FLAW = 1
MAX. AMPL. = +6
A COORD. = 223
B COORD. = 44
CRT. DIST. = 44
ANGLE = 60
PLATE BOTTOM
SIDE = STAMPED
SKIP = 1/2
BEAM WIDTH (mm)
1 dB VERTX = 4 mm
3 dB VERTX = 8 mm
6 dB VERTX = 13 mm (19)
100% VERTX = 13 mm
50% VERTX = 13 mm
12 dB VERTX = 23 mm (26)
14 dB VERTX = 25 mm
CRT DISTANCE mm
AMPLITUDE
B COORDINATE (mm)

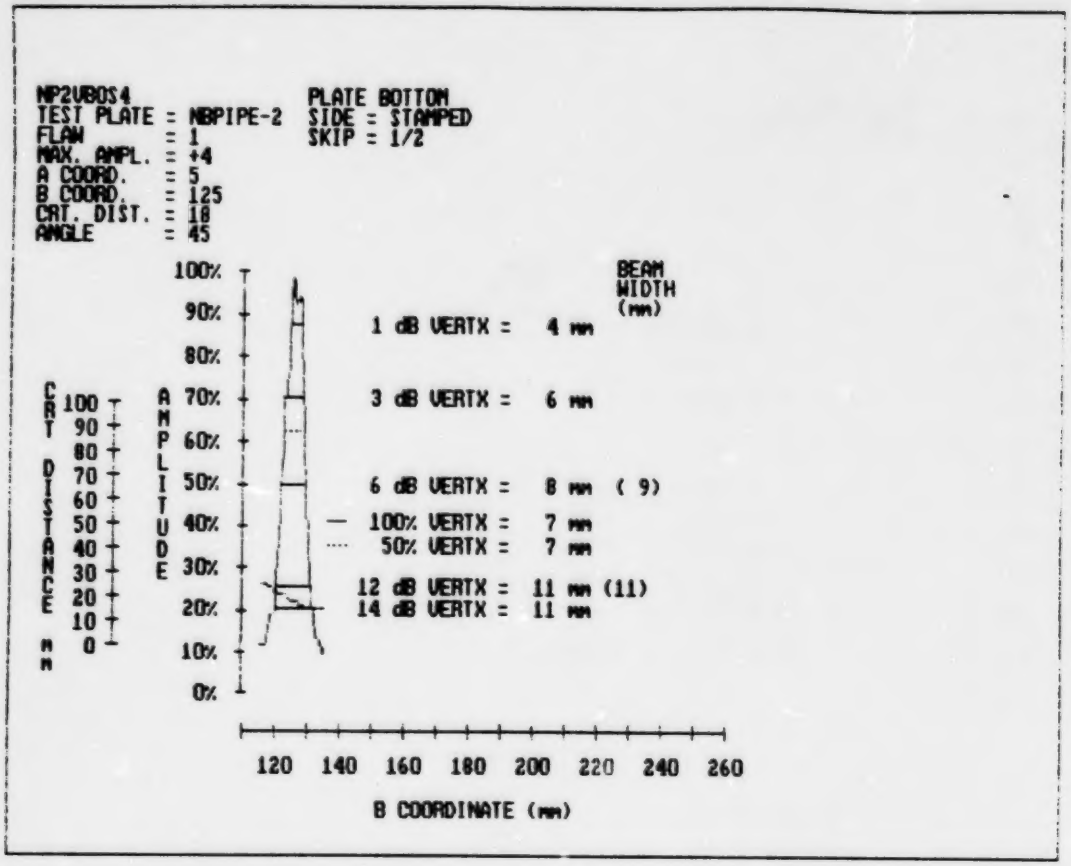
ACTUAL VERTICAL EXTENT EQUALS 11MM

APPENDIX C

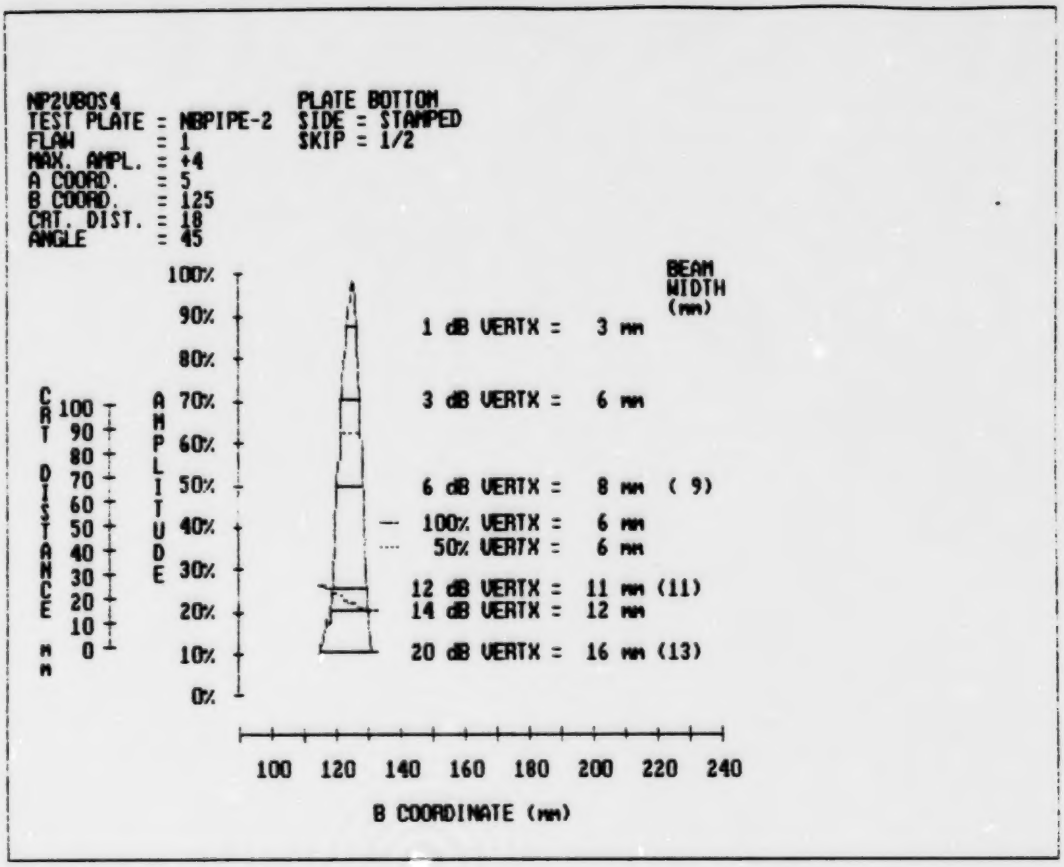
Ultrasonic Scans Obtained From Flaw #1 NBPIPE - 2


MP2VBOS4
TEST PLATE = NBPIPE-2
FLAW = 1
MAX. AMPL. = +4
A COORD. = 5
B COORD. = 125
CRT. DIST. = 18
ANGLE = 45
PLATE BOTTOM
SIDE = STAMPED
SKIP = 1/2
BEAM WIDTH (mm)
1 dB VERTX = 4 mm
3 dB VERTX = 7 mm
6 dB VERTX = 10 mm (9)
100% VERTX = 8 mm
50% VERTX = 8 mm
12 dB VERTX = 11 mm (11)
14 dB VERTX = 13 mm
20 dB VERTX = 19 mm (13)
CRT DISTANCE mm
AMPLITUDE
100 90 80 70 60 50 40 30 20 10 0
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
100 120 140 160 180 200 220 240
B COORDINATE (mm)

ACTUAL VERTICAL EXTENT EQUALS 11MM



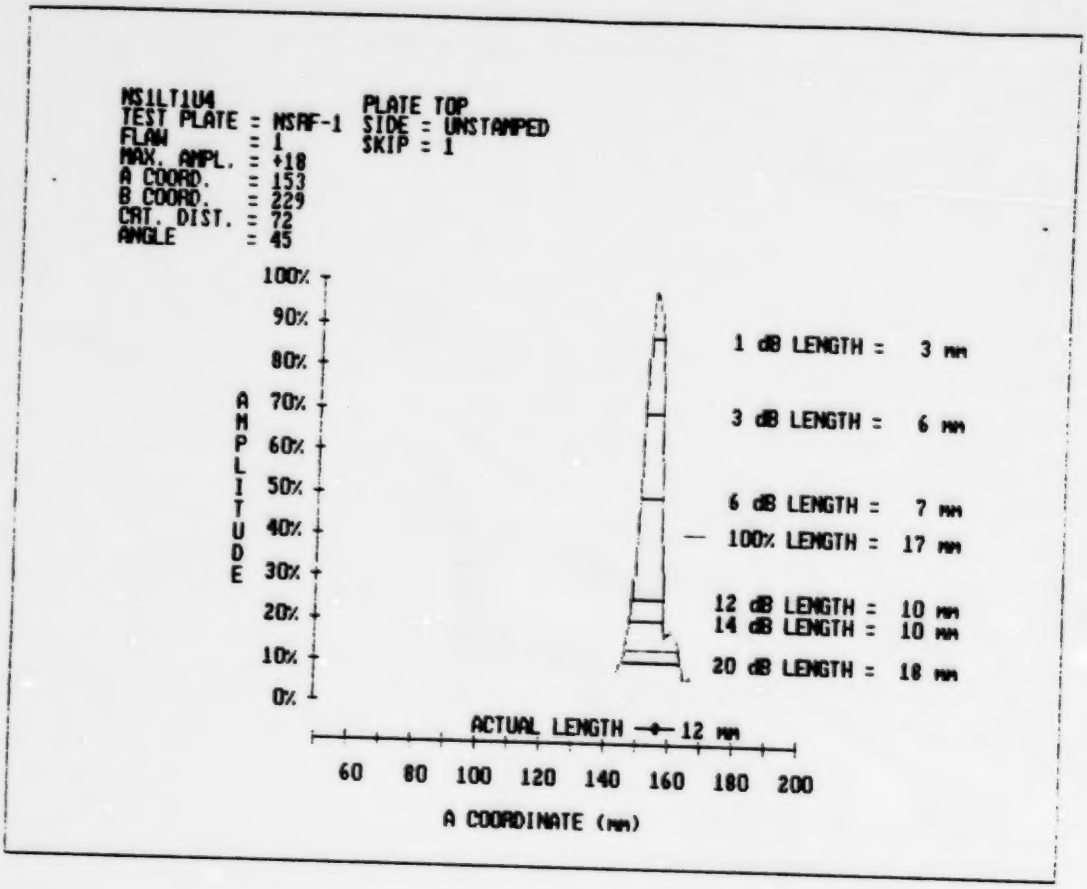
ACTUAL VERTICAL EXTENT EQUALS 11MM

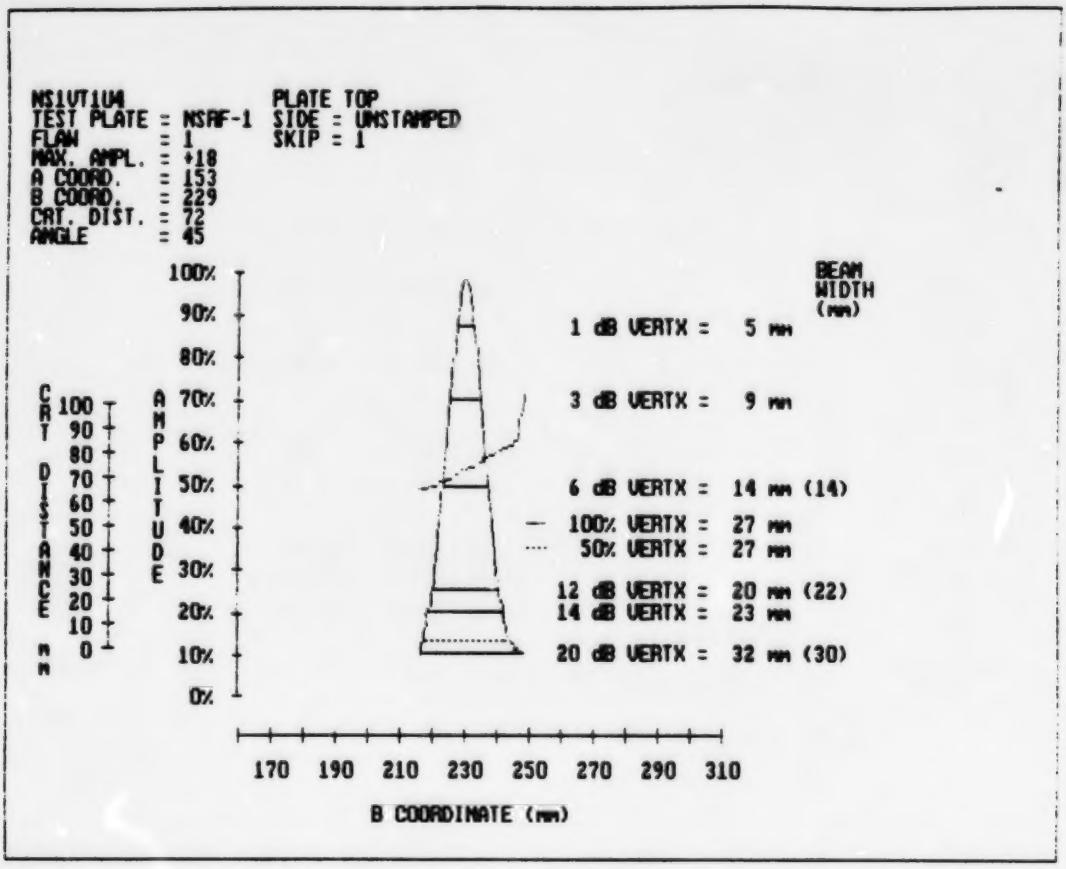

NP2VBOS4
TEST PLATE = NBPIPE-2
FLAW = 1
MAX. AMPL. = +4
A COORD. = 5
B COORD. = 125
CRT. DIST. = 18
ANGLE = 45
PLATE BOTTOM
SIDE = STAMPED
SKIP = 1/2
BEAM WIDTH (mm)
1 dB VERTX = 3 mm
3 dB VERTX = 6 mm
6 dB VERTX = 8 mm (9)
100% VERTX = 6 mm
50% VERTX = 6 mm
12 dB VERTX = 11 mm (11)
14 dB VERTX = 12 mm
20 dB VERTX = 16 mm (13)
CRT DISTANCE mm
AMPLITUDE
100 90 80 70 60 50 40 30 20 10 0
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
100 120 140 160 180 200 220 240
B COORDINATE (mm)

ACTUAL VERTICAL EXTENT EQUALS 11MM

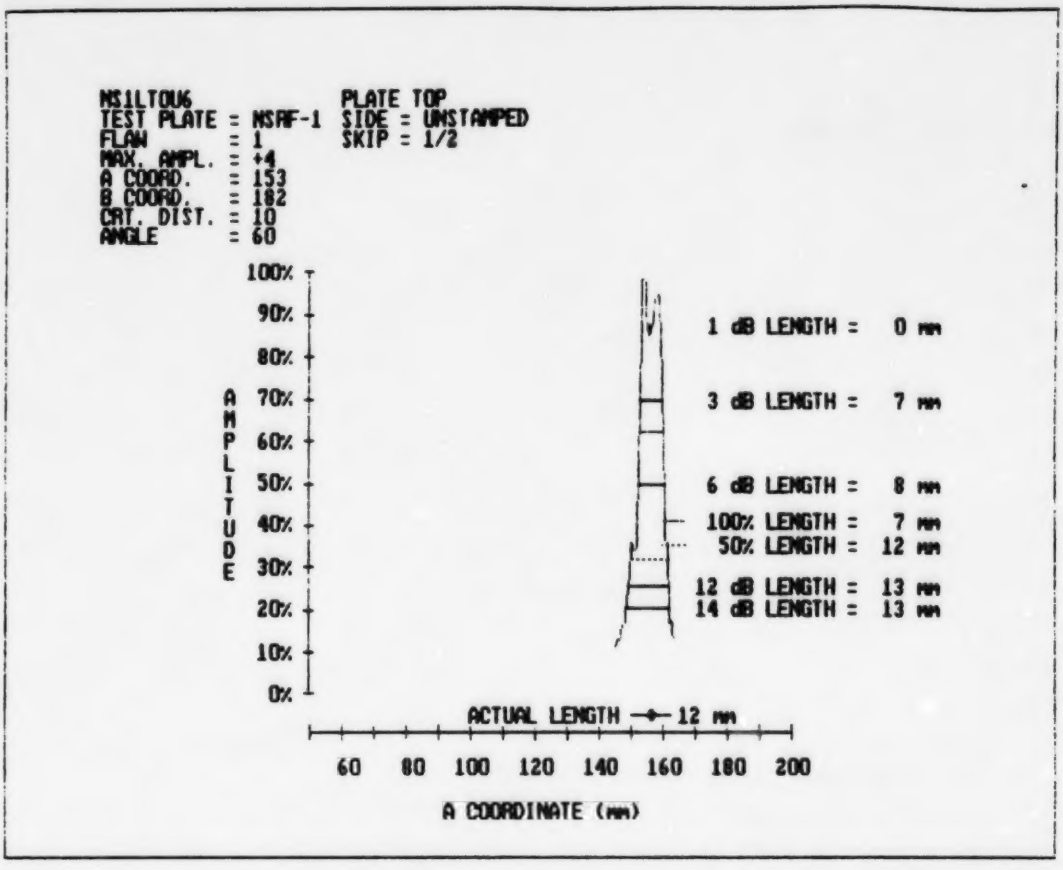
APPENDIX D

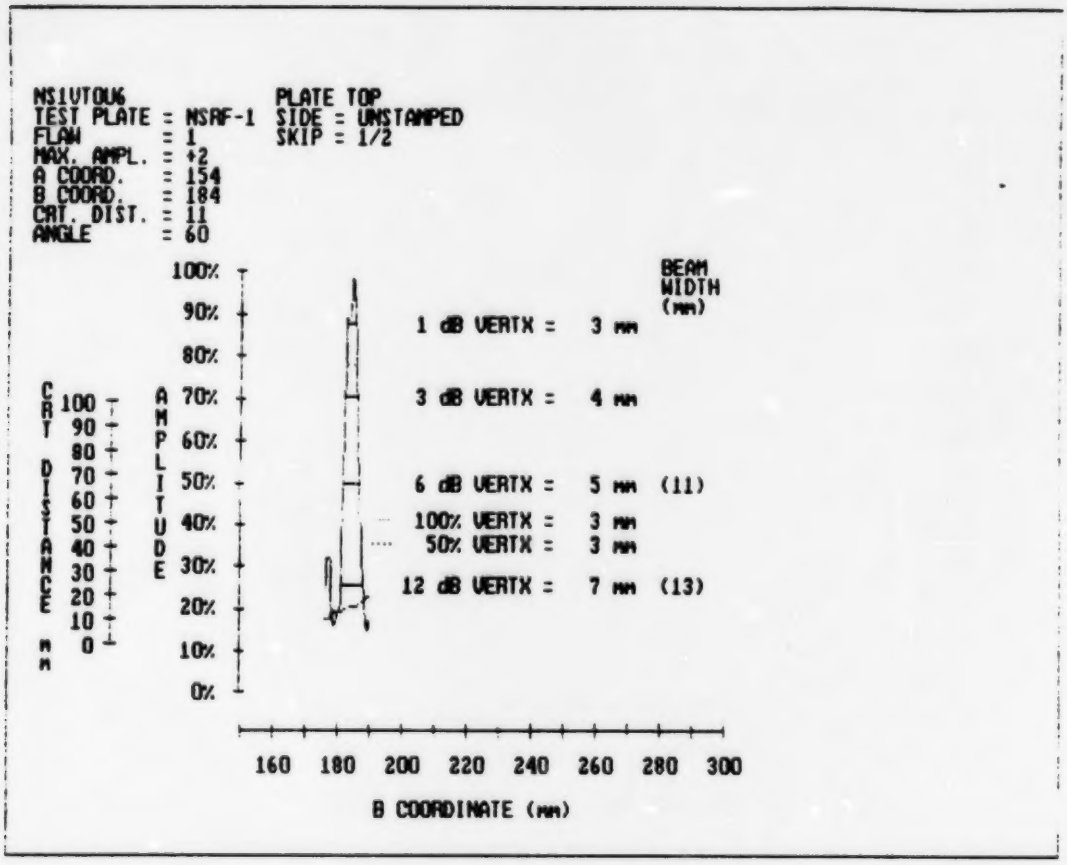
Ultrasonic Scans Obtained From Flaw #1 NSRF - 1


MSILT1U4
TEST PLATE = MSRF-1
FLAW = 1
MAX. AMPL. = +18
A COORD. = 153
B COORD. = 229
CRT. DIST. = 72
ANGLE = 45
PLATE TOP
SIDE = UNSTAMPED
SKIP = 1
AMPLITUDE
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 dB LENGTH = 3 mm
3 dB LENGTH = 6 mm
6 dB LENGTH = 7 mm
100% LENGTH = 17 mm
12 dB LENGTH = 10 mm
14 dB LENGTH = 10 mm
20 dB LENGTH = 18 mm
ACTUAL LENGTH → 12 mm
60 80 100 120 140 160 180 200
A COORDINATE (mm)

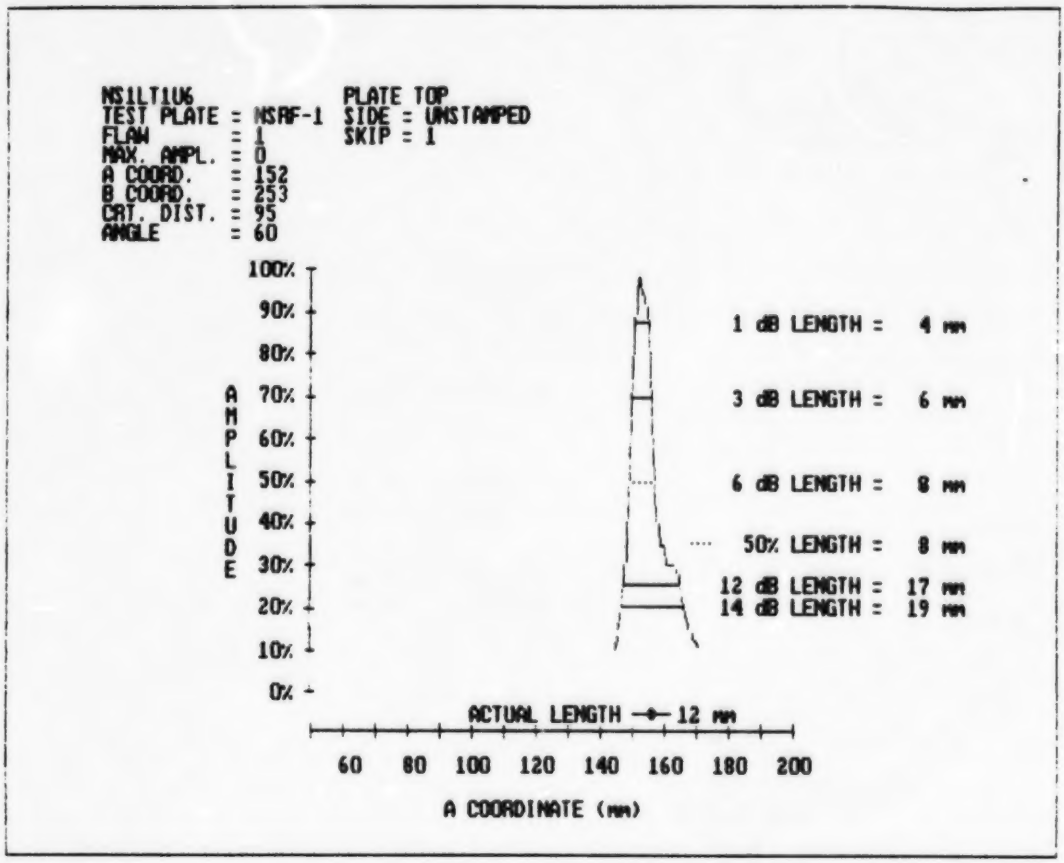


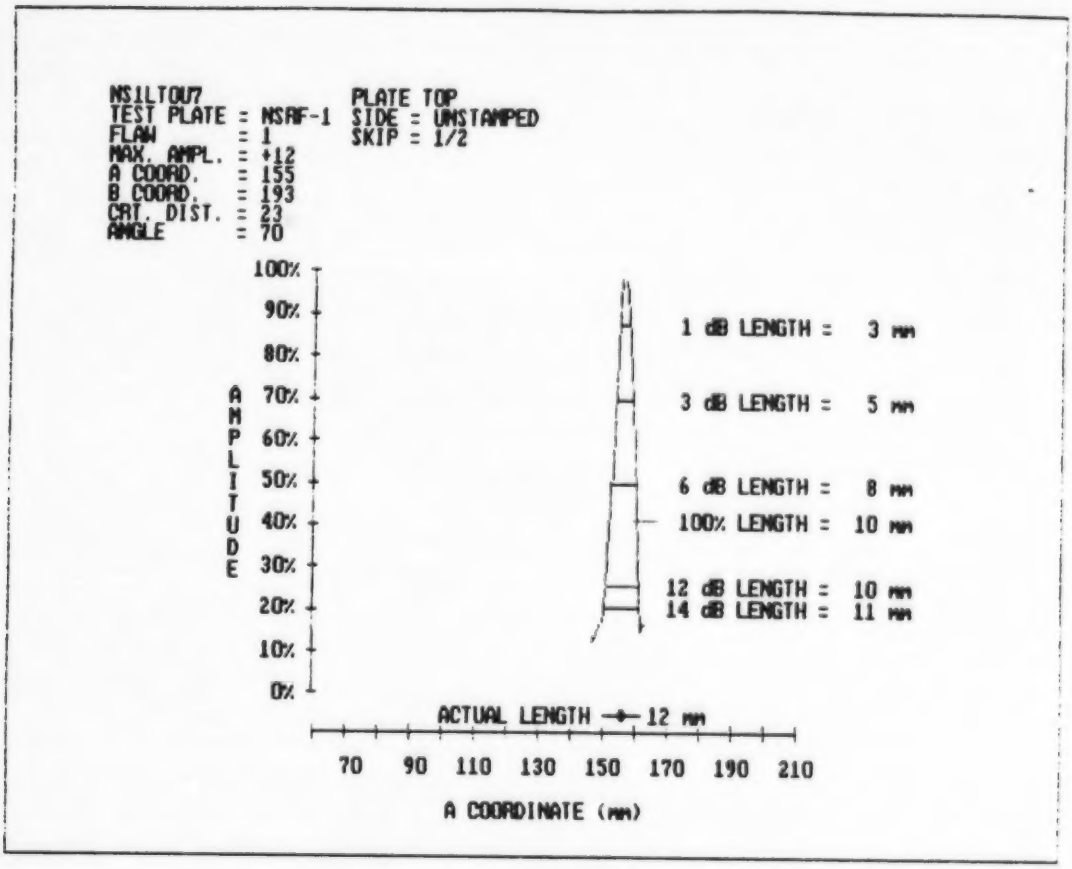
ACTUAL VERTICAL EXTENT EQUALS 7.5MM

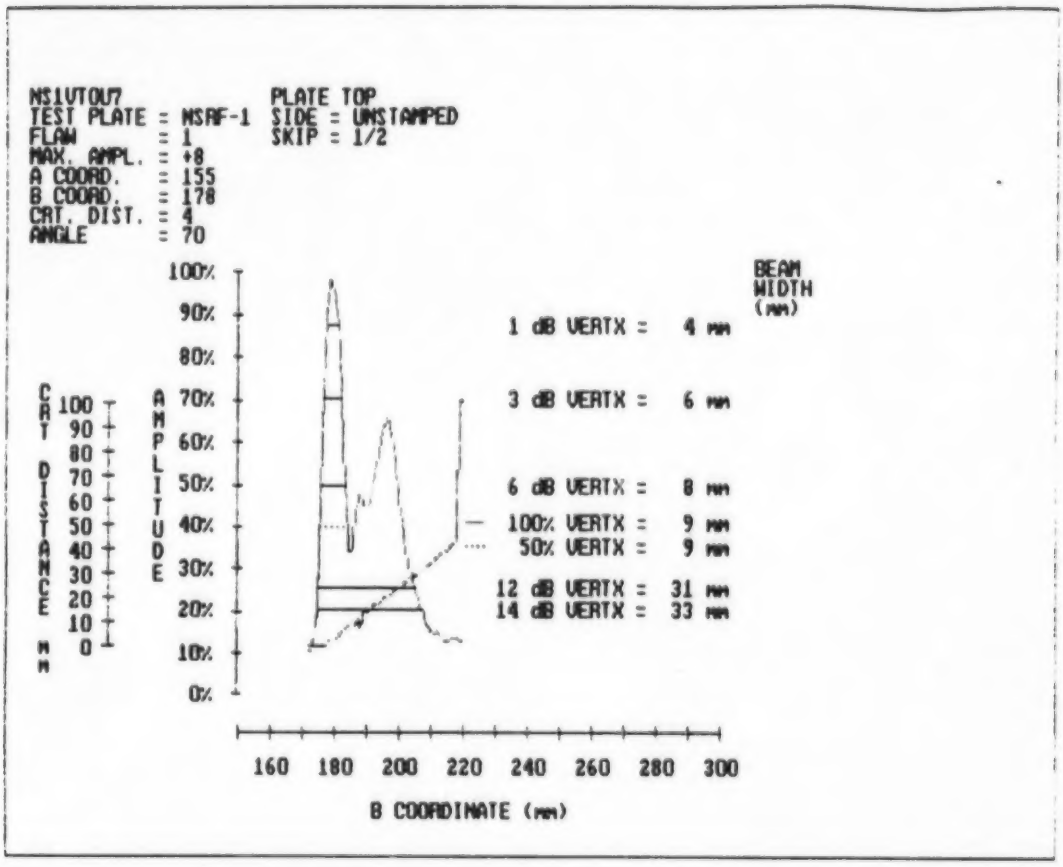

MS1LTOU6
TEST PLATE = NSRF-1
FLAW = 1
MAX. AMPL. = +4
A COORD. = 153
B COORD. = 182
CRT. DIST. = 10
ANGLE = 60
PLATE TOP
SIDE = UNSTAMPED
SKIP = 1/2
AMPLITUDE
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 dB LENGTH = 0 mm
3 dB LENGTH = 7 mm
6 dB LENGTH = 8 mm
100% LENGTH = 7 mm
50% LENGTH = 12 mm
12 dB LENGTH = 13 mm
14 dB LENGTH = 13 mm
ACTUAL LENGTH → 12 mm
60 80 100 120 140 160 180 200
A COORDINATE (mm)



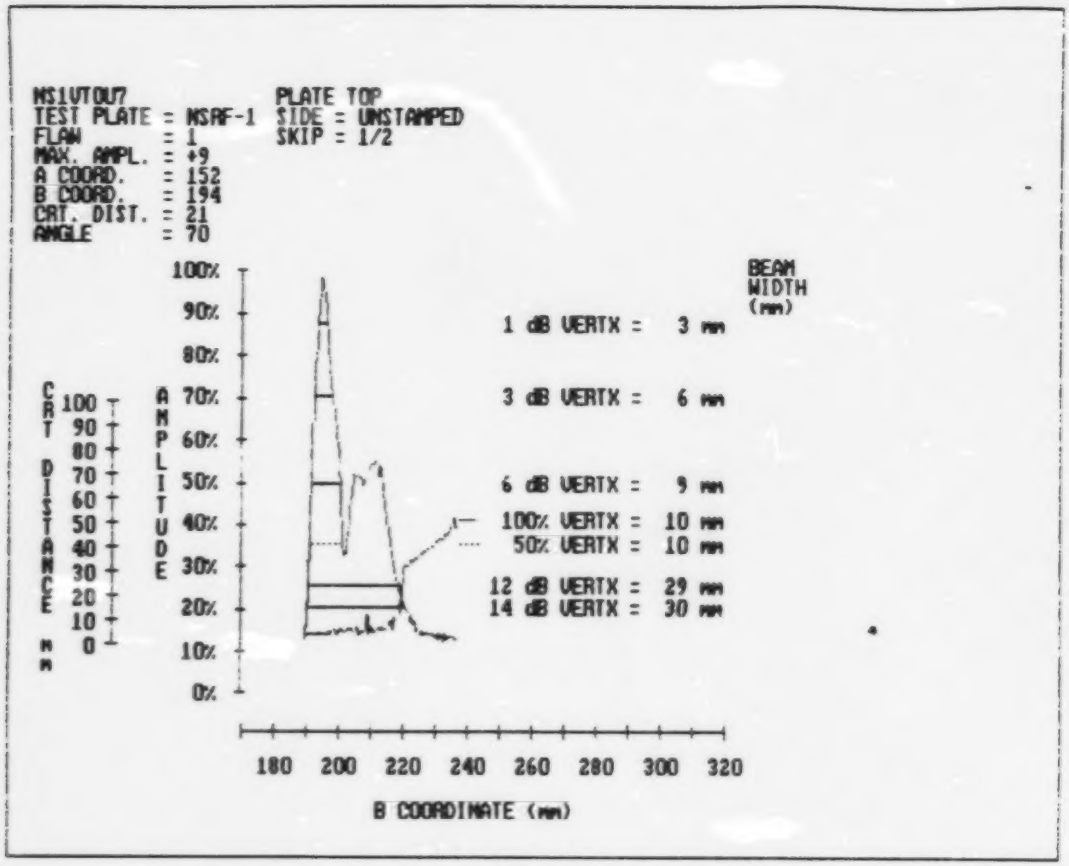
ACTUAL VERTICAL EXTENT EQUALS 7.5MM


NSILT1U6
TEST PLATE = NSRF-1
FLAW = 1
MAX. AMPL. = 0
A COORD. = 152
B COORD. = 253
CRT. DIST. = 95
ANGLE = 60
PLATE TOP
SIDE = UNSTAMPED
SKIP = 1
AMPLITUDE
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 dB LENGTH = 4 mm
3 dB LENGTH = 6 mm
6 dB LENGTH = 8 mm
50% LENGTH = 8 mm
12 dB LENGTH = 17 mm
14 dB LENGTH = 19 mm
ACTUAL LENGTH 12 mm
60 80 100 120 140 160 180 200
A COORDINATE (mm)

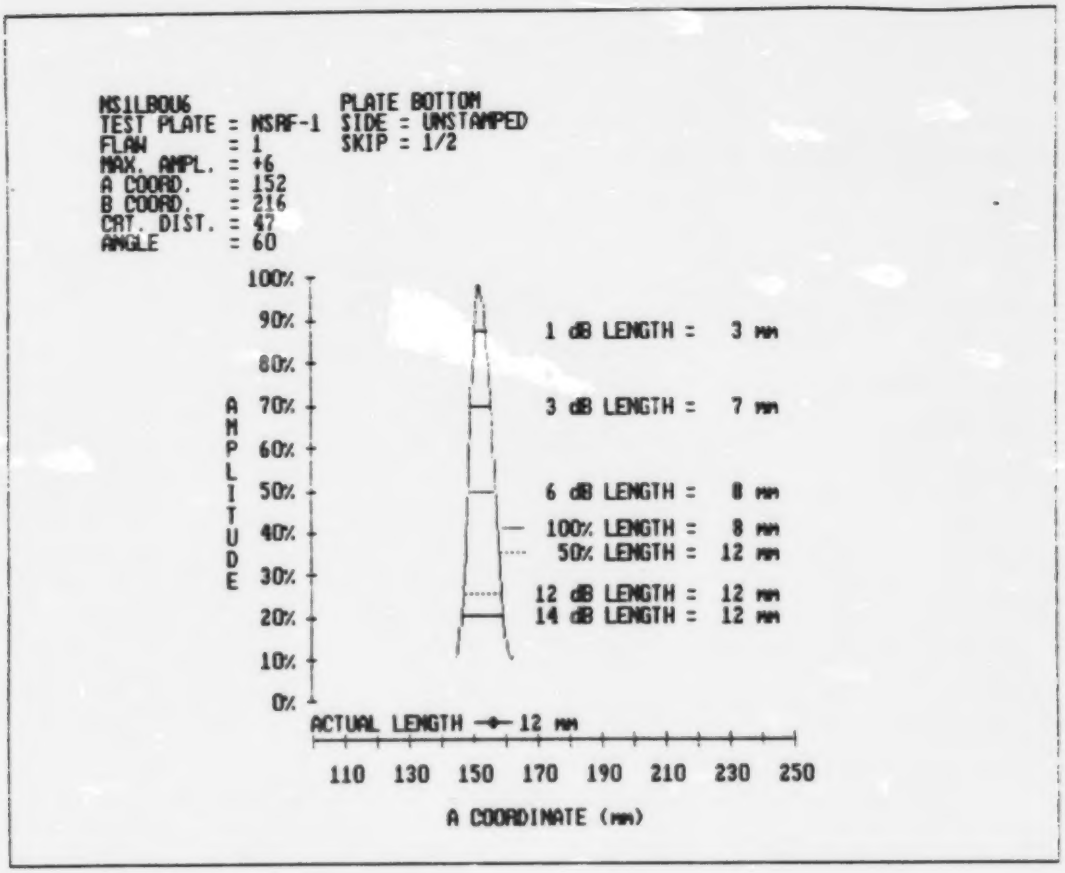

NSILTOU7
TEST PLATE = NSRF-1
FLAW = 1
MAX. AMPL. = +12
A COORD. = 155
B COORD. = 193
CRT. DIST. = 23
ANGLE = 70
PLATE TOP
SIDE = UNSTAMPED
SKIP = 1/2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 3 mm
3 dB LENGTH = 5 mm
6 dB LENGTH = 8 mm
100% LENGTH = 10 mm
12 dB LENGTH = 10 mm
14 dB LENGTH = 11 mm
ACTUAL LENGTH 12 mm
70
90
110
130
150
170
190
210
A COORDINATE (mm)

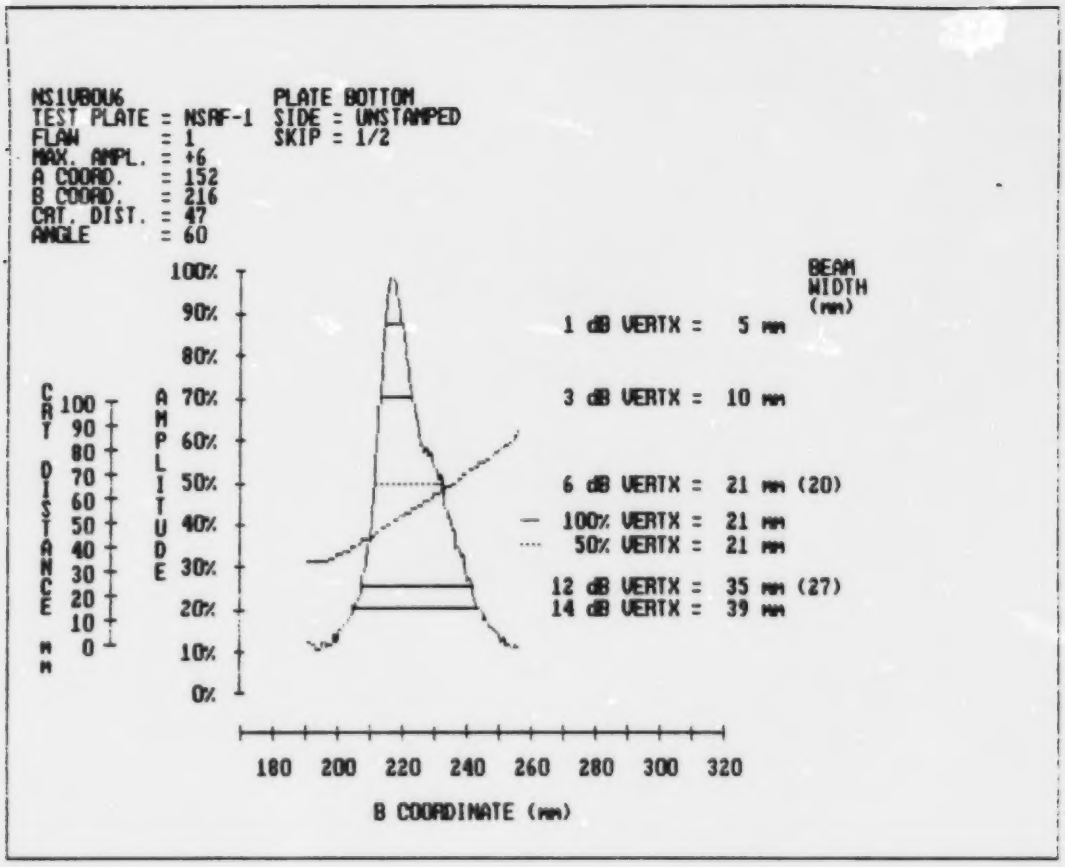


ACTUAL VERTICAL EXTENT EQUALS 7.5MM

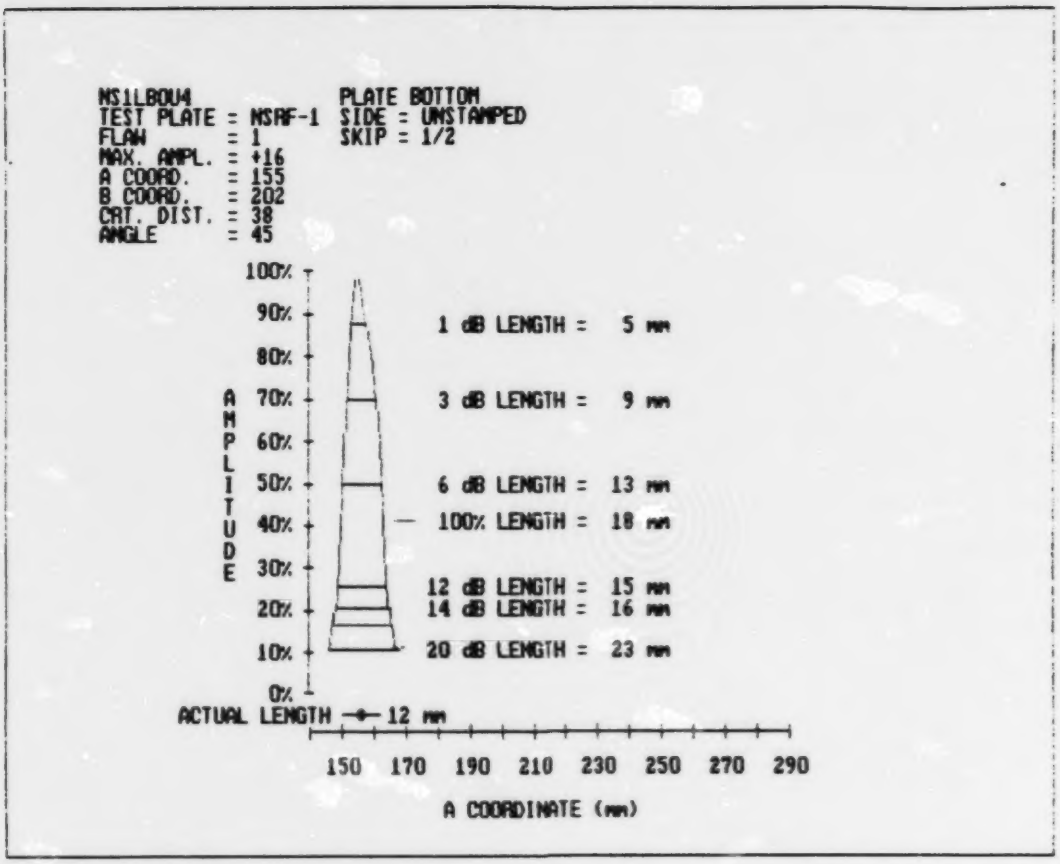


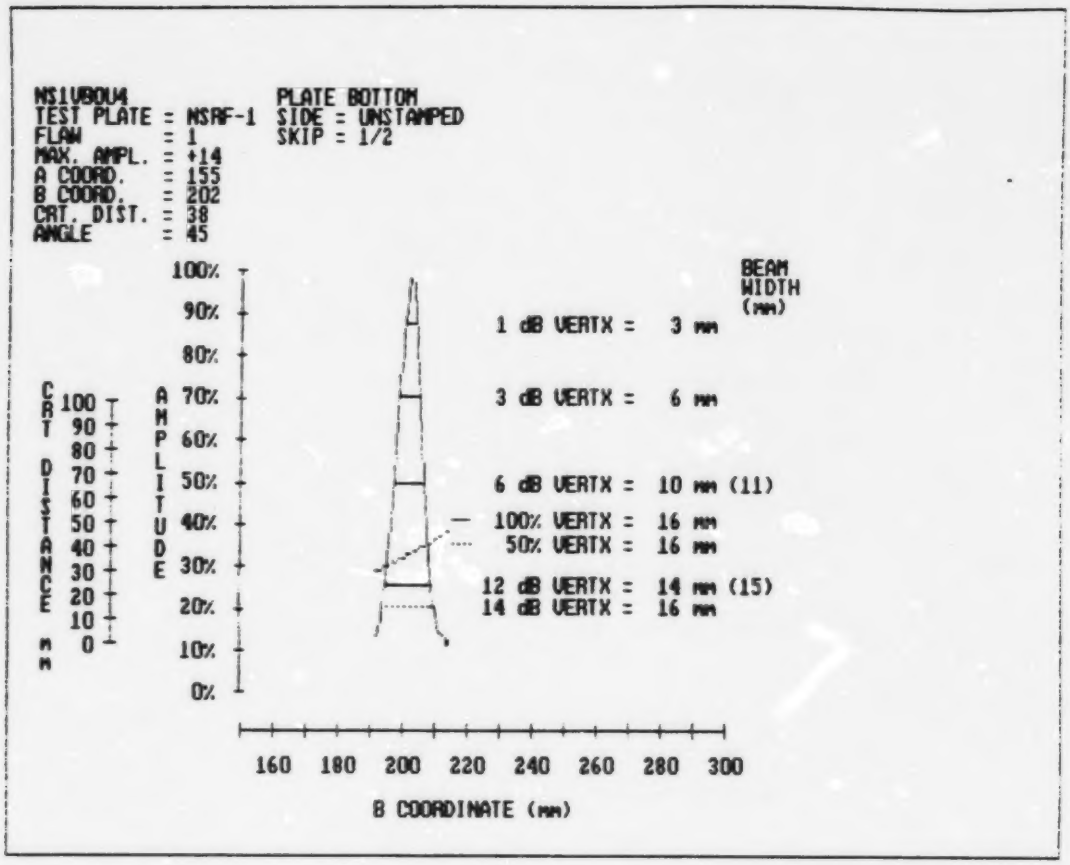
ACTUAL VERTICAL EXTENT EQUALS 7.5MM


MS1LBOU6
TEST PLATE = MSRF-1
FLAW = 1
MAX. AMPL. = +6
A COORD. = 152
B COORD. = 216
CRT. DIST. = 47
ANGLE = 60
PLATE BOTTOM
SIDE = UNSTAMPED
SKIP = 1/2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 3 mm
3 dB LENGTH = 7 mm
6 dB LENGTH = 8 mm
100% LENGTH = 8 mm
50% LENGTH = 12 mm
12 dB LENGTH = 12 mm
14 dB LENGTH = 12 mm
ACTUAL LENGTH → 12 mm
110 130 150 170 190 210 230 250
A COORDINATE (mm)


NS1VBOU6
TEST PLATE = NSAF-1
FLAW = 1
MAX. AMPL. = +6
A COORD. = 152
B COORD. = 216
CRT. DIST. = 47
ANGLE = 60
PLATE BOTTOM
SIDE = UNSTAMPED
SKIP = 1/2
BEAM WIDTH (mm)
1 dB VERTX = 5 mm
3 dB VERTX = 10 mm
6 dB VERTX = 21 mm (20)
100% VERTX = 21 mm
50% VERTX = 21 mm
12 dB VERTX = 35 mm (27)
14 dB VERTX = 39 mm
CRT DISTANCE mm
AMPLITUDE
B COORDINATE (mm)

ACTUAL VERTICAL EXTENT EQUALS 7.5MM

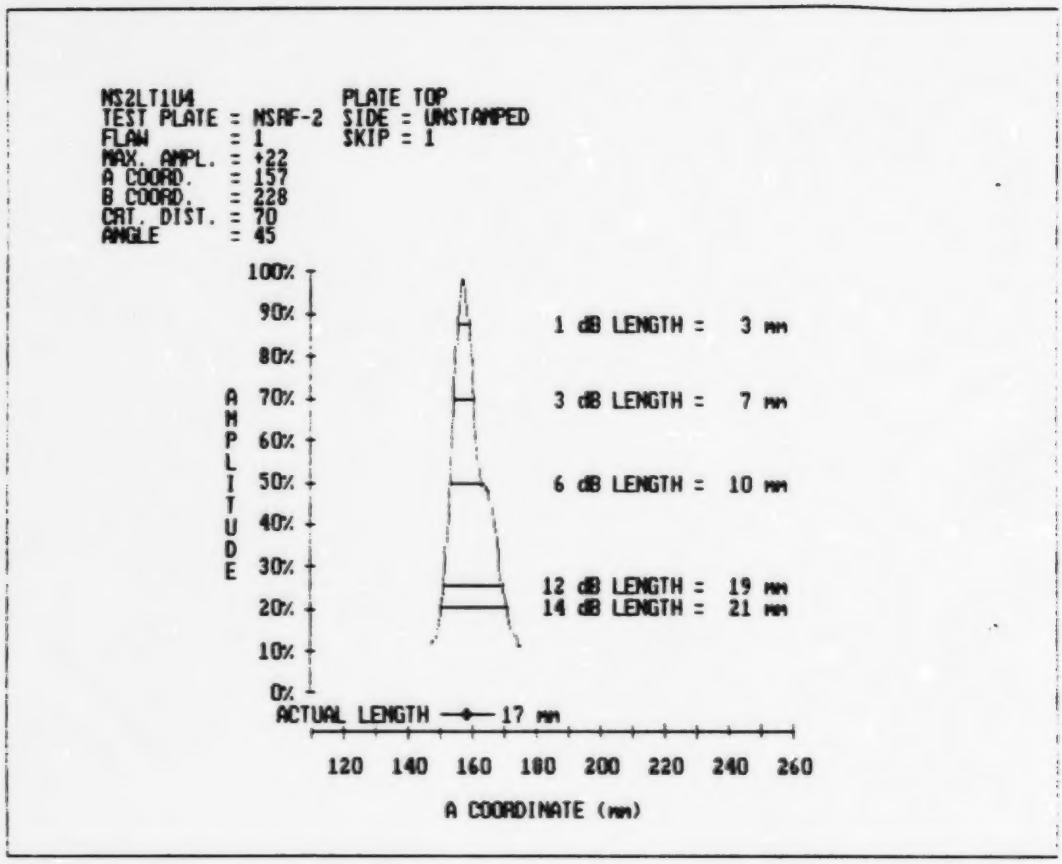

MS1LBOU4
TEST PLATE = MSRF-1
FLAW = 1
MAX. AMPL. = +16
A COORD. = 155
B COORD. = 202
CRT. DIST. = 38
ANGLE = 45
PLATE BOTTOM
SIDE = UNSTAMPED
SKIP = 1/2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 5 mm
3 dB LENGTH = 9 mm
6 dB LENGTH = 13 mm
100% LENGTH = 18 mm
12 dB LENGTH = 15 mm
14 dB LENGTH = 16 mm
20 dB LENGTH = 23 mm
ACTUAL LENGTH 12 mm
150 170 190 210 230 250 270 290
A COORDINATE (mm)

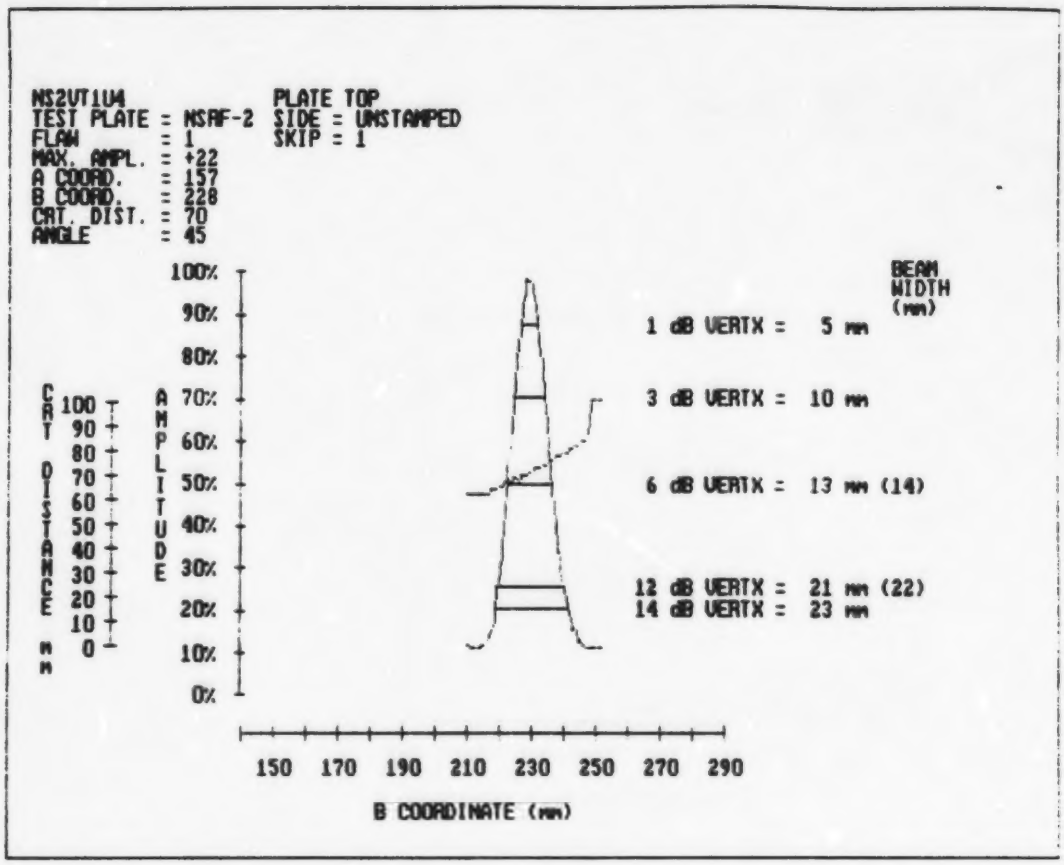


ACTUAL VERTICAL EXTENT EQUALS 7.5MM

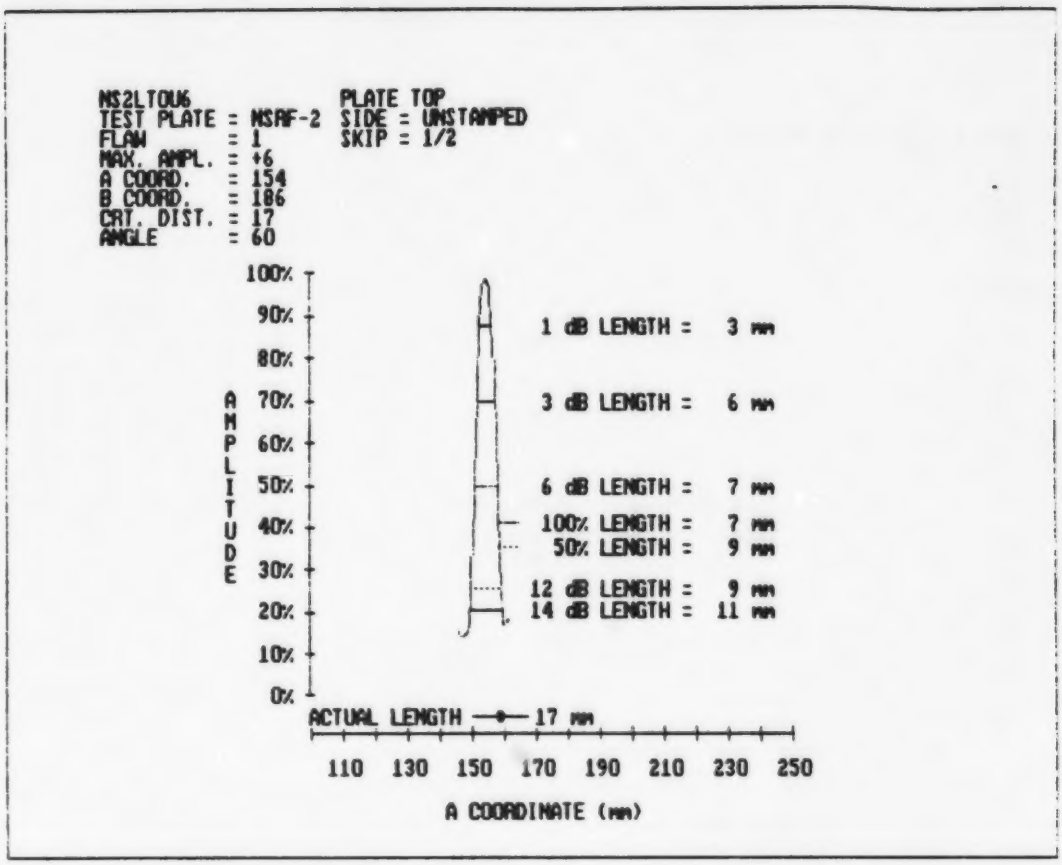
APPENDIX E

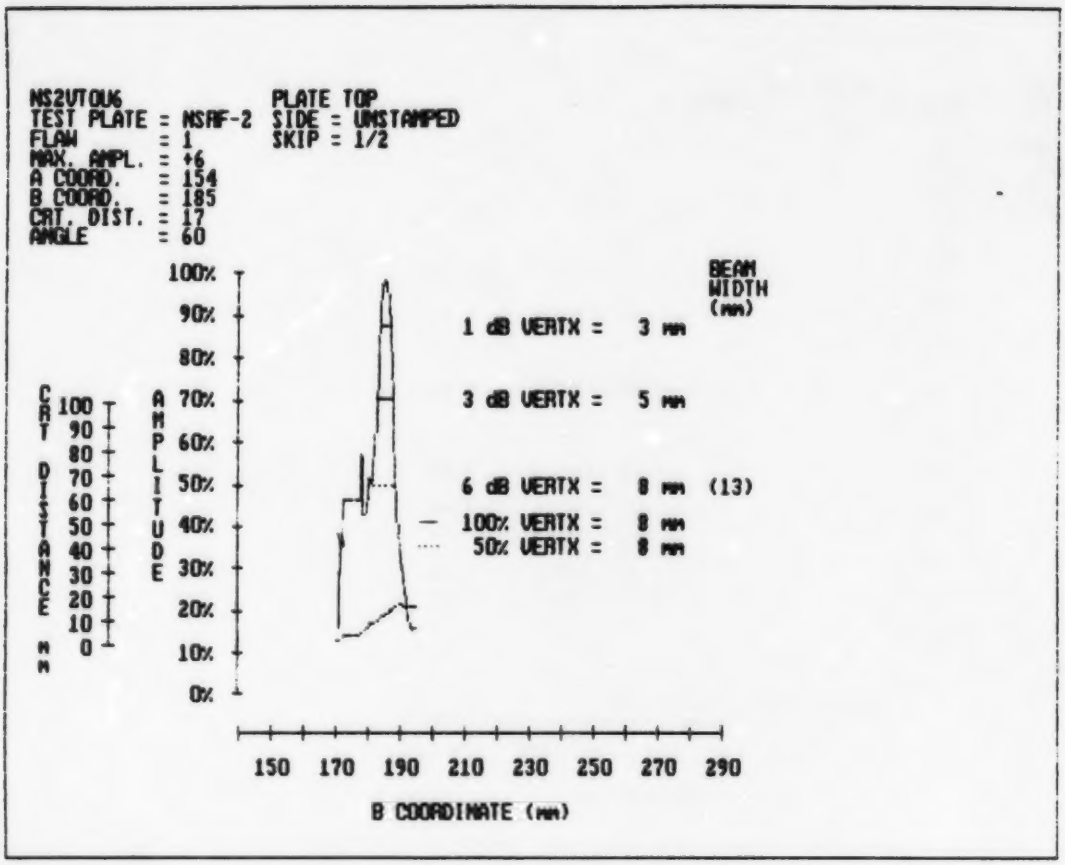
Ultrasonic Scans Obtained From
Fl[illegible] #1 NSRF - 2


MS2LT1U4
PLATE TOP
TEST PLATE = MSRF-2
SIDE = UNSTAMPED
FLAW = 1
SKIP = 1
MAX. AMPL. = +22
A COORD. = 157
B COORD. = 228
CRT. DIST. = 70
ANGLE = 45
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 3 mm
3 dB LENGTH = 7 mm
6 dB LENGTH = 10 mm
12 dB LENGTH = 19 mm
14 dB LENGTH = 21 mm
ACTUAL LENGTH — 17 mm
120 140 160 180 200 220 240 260
A COORDINATE (mm)

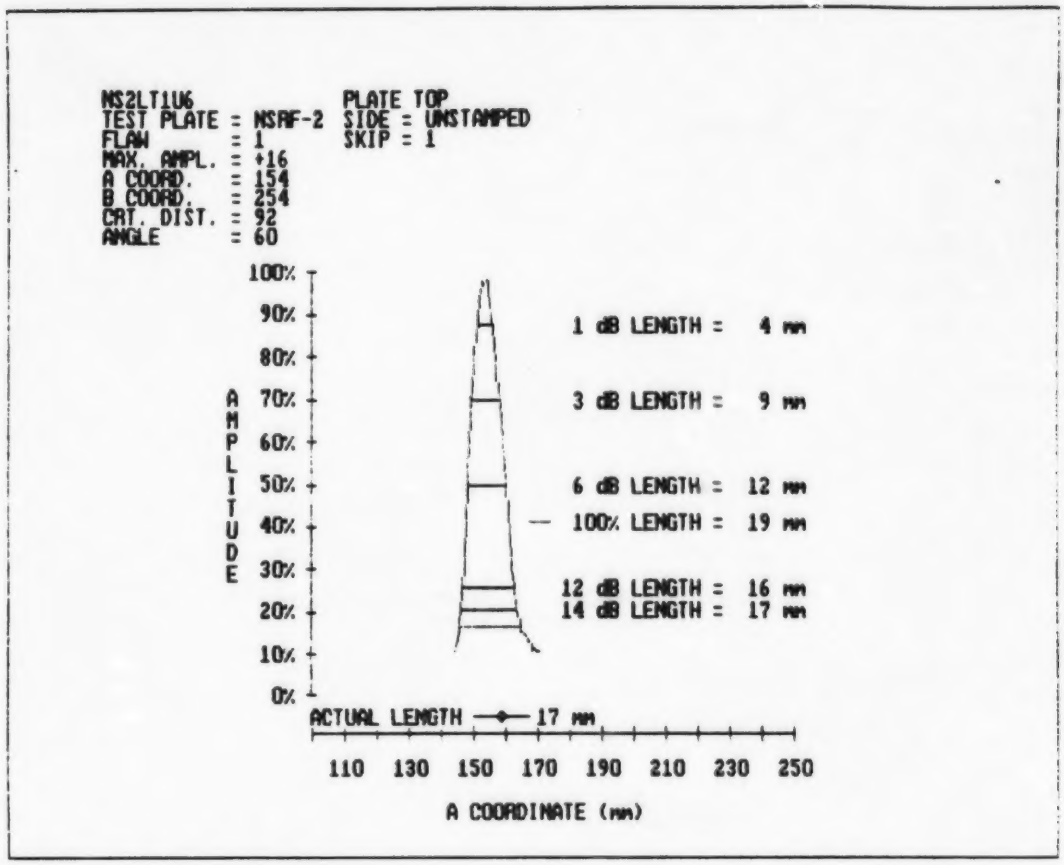


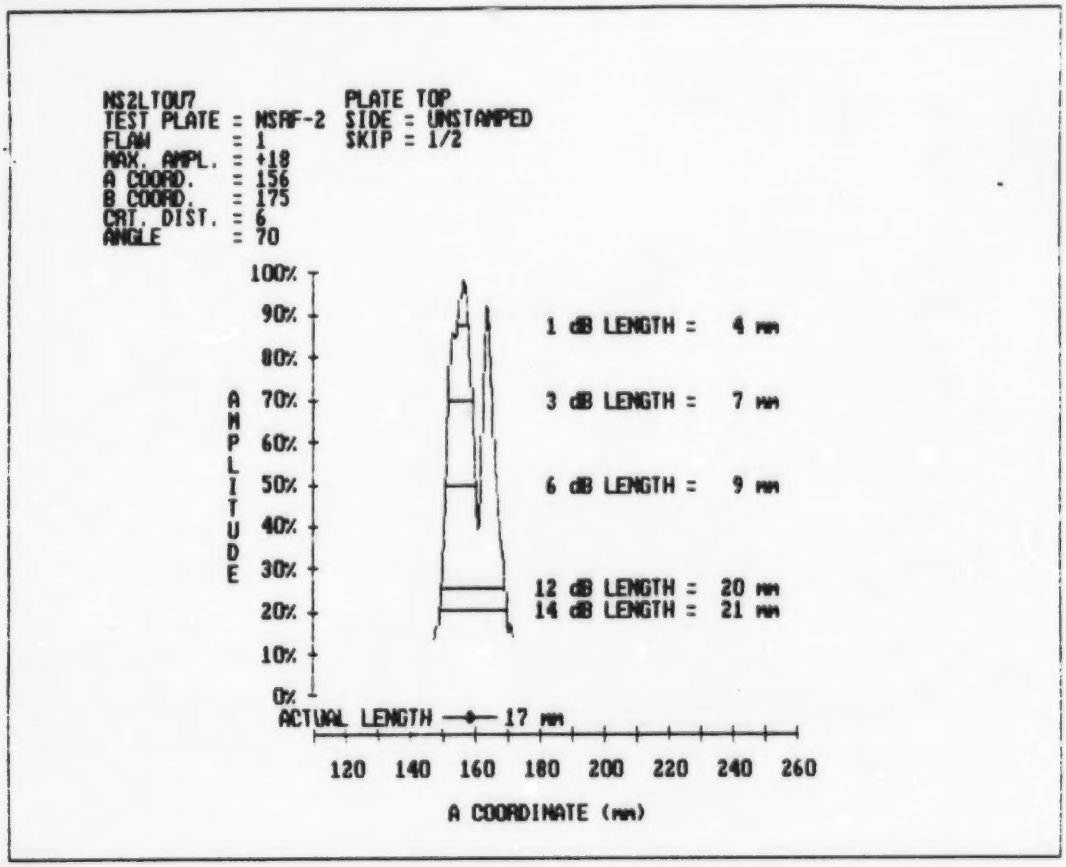
ACTUAL VERTICAL EXTENT EQUALS 7MM

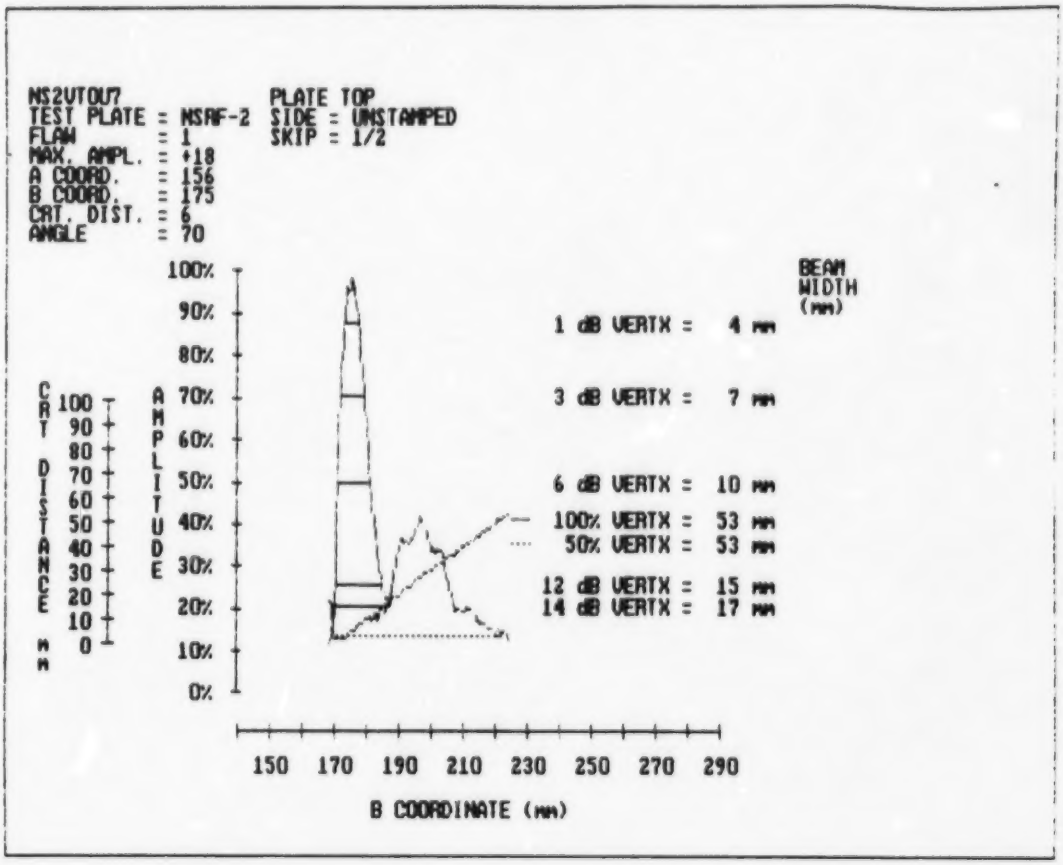

NS2LTOU6
TEST PLATE = NSRF-2
FLAW = 1
MAX. AMPL. = +6
A COORD. = 154
B COORD. = 186
CRT. DIST. = 17
ANGLE = 60
PLATE TOP
SIDE = UNSTAMPED
SKIP = 1/2
AMPLITUDE
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 dB LENGTH = 3 mm
3 dB LENGTH = 6 mm
6 dB LENGTH = 7 mm
100% LENGTH = 7 mm
50% LENGTH = 9 mm
12 dB LENGTH = 9 mm
14 dB LENGTH = 11 mm
ACTUAL LENGTH — 17 mm
110 130 150 170 190 210 230 250
A COORDINATE (mm)



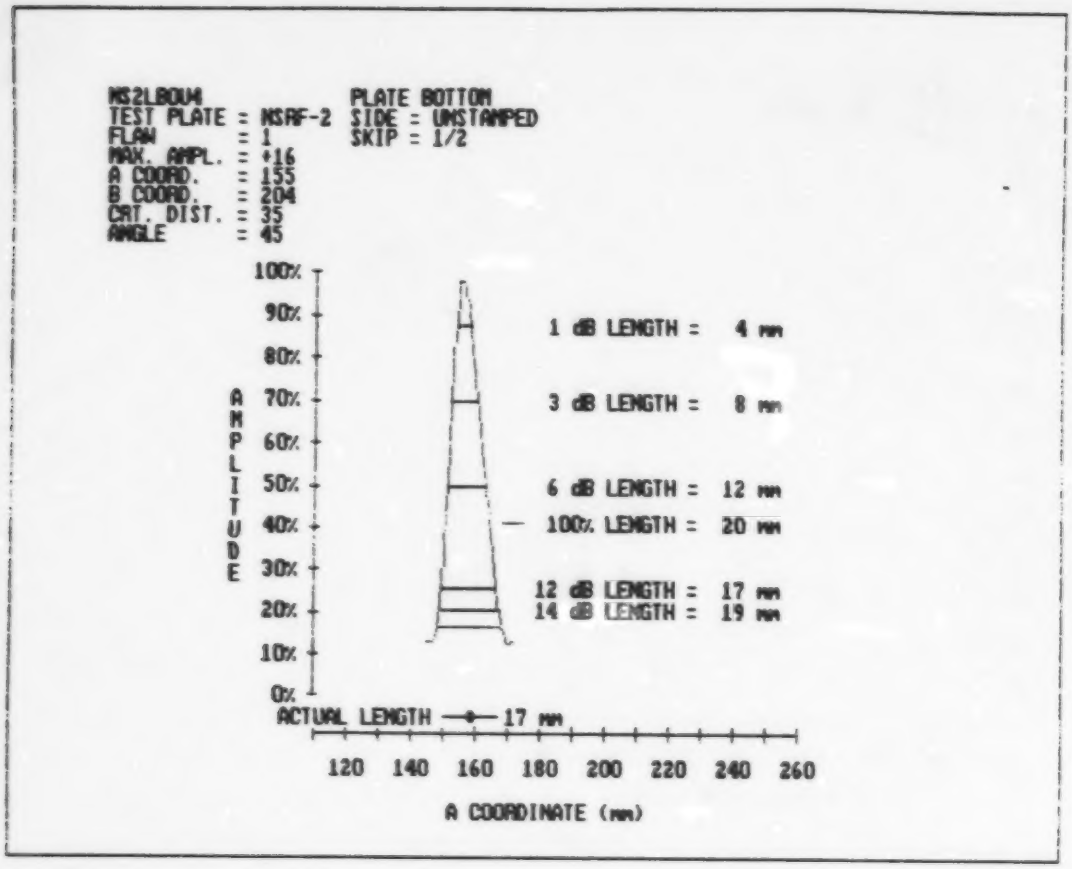
ACTUAL VERTICAL EXTENT EQUALS 7MM

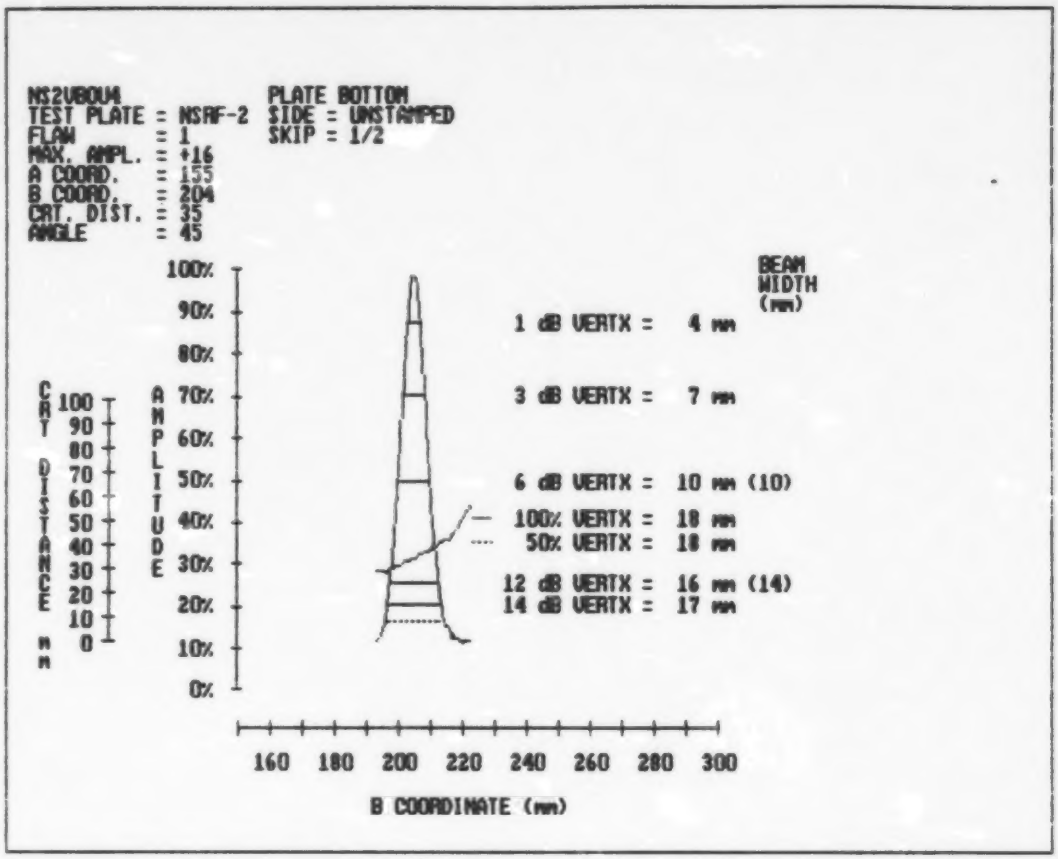

NS2LT1U6
TEST PLATE = NSRF-2
FLAW = 1
MAX. AMPL. = +16
A COORD. = 154
B COORD. = 254
CRT. DIST. = 92
ANGLE = 60
PLATE TOP
SIDE = UNSTAMPED
SKIP = 1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 4 mm
3 dB LENGTH = 9 mm
6 dB LENGTH = 12 mm
100% LENGTH = 19 mm
12 dB LENGTH = 16 mm
14 dB LENGTH = 17 mm
ACTUAL LENGTH 17 mm
110 130 150 170 190 210 230 250
A COORDINATE (mm)


NS2LTOU7
TEST PLATE = NSRF-2
FLAW = 1
MAX. AMPL. = +18
A COORD. = 156
B COORD. = 175
CRT. DIST. = 6
ANGLE = 70
PLATE TOP
SIDE = UNSTAMPED
SKIP = 1/2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 4 mm
3 dB LENGTH = 7 mm
6 dB LENGTH = 9 mm
12 dB LENGTH = 20 mm
14 dB LENGTH = 21 mm
ACTUAL LENGTH — 17 mm
120 140 160 180 200 220 240 260
A COORDINATE (mm)

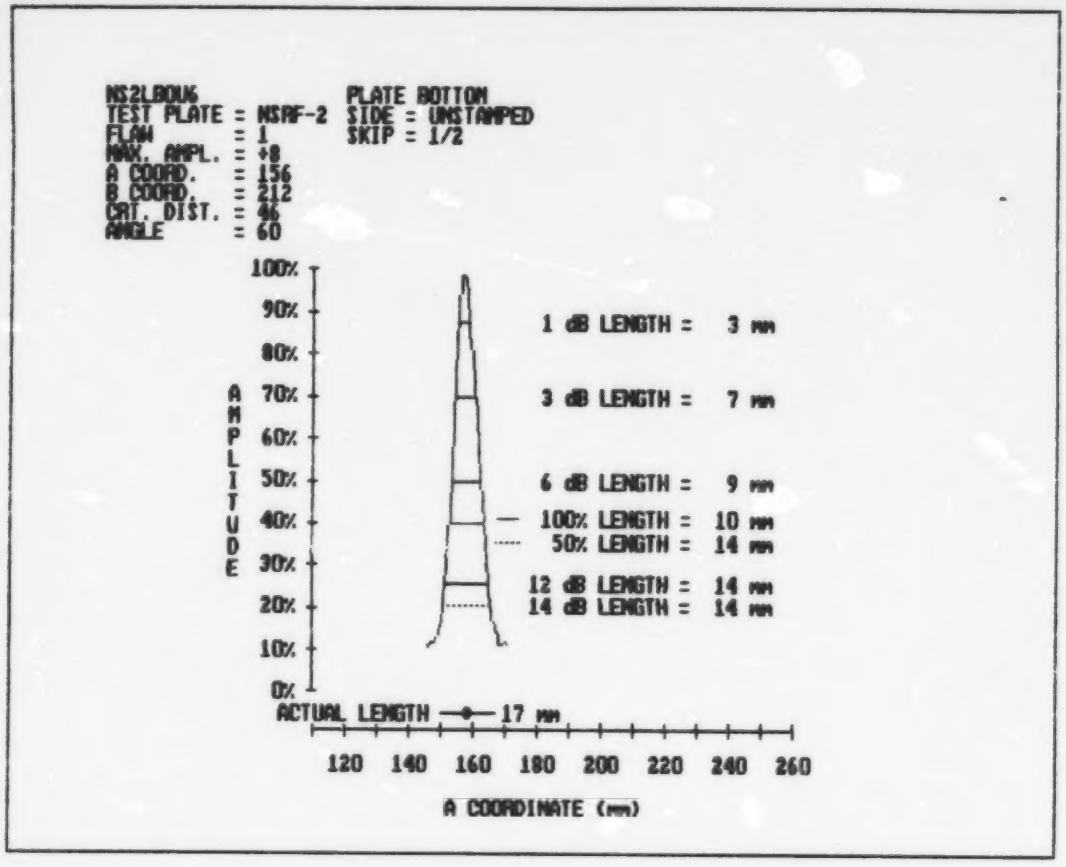


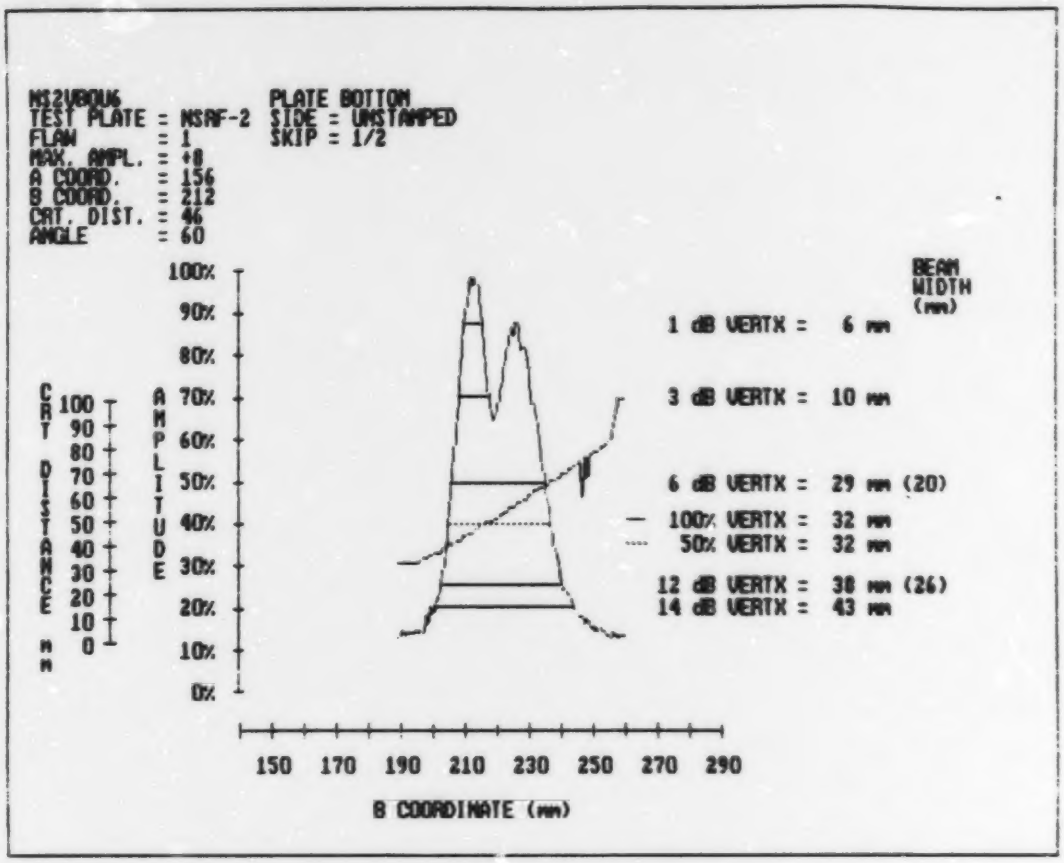
ACTUAL VERTICAL EXTENT EQUALS 7MM


MS2LBOUH
TEST PLATE = MSRF-2
FLAW = 1
MAX. AMPL. = +16
A COORD. = 155
B COORD. = 204
CRT. DIST. = 35
ANGLE = 45
PLATE BOTTOM
SIDE = UNSTAMPED
SKIP = 1/2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AMPLITUDE
1 dB LENGTH = 4 mm
3 dB LENGTH = 8 mm
6 dB LENGTH = 12 mm
100% LENGTH = 20 mm
12 dB LENGTH = 17 mm
14 dB LENGTH = 19 mm
ACTUAL LENGTH — 17 mm
120 140 160 180 200 220 240 260
A COORDINATE (mm)



ACTUAL VERTICAL EXTENT EQUALS 7MM


NS2LBOU6
TEST PLATE = NSRF-2
FLAW = 1
MAX. AMPL. = +8
A COORD. = 156
B COORD. = 212
CRT. DIST. = 46
ANGLE = 60
PLATE BOTTOM
SIDE = UNSTAMPED
SKIP = 1/2
1 dB LENGTH = 3 mm
3 dB LENGTH = 7 mm
6 dB LENGTH = 9 mm
100% LENGTH = 10 mm
50% LENGTH = 14 mm
12 dB LENGTH = 14 mm
14 dB LENGTH = 14 mm
AMPLITUDE
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
ACTUAL LENGTH 17 mm
120 140 160 180 200 220 240 260
A COORDINATE (mm)



ACTUAL VERTICAL EXTENT EQUALS 7MM